PEDAL TO THE METAL: ELECTRIC VEHICLE BATTERIES AND THE CRITICAL MINERALS SUPPLY

FIELD HEARING

BEFORE THE

SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

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C O N T E N T S

April 21, 2022

PEDAL TO THE METAL: ELECTRIC VEHICLE BATTERIES AND THE CRITICAL MINERALS SUPPLY

THURSDAY, APRIL 21, 2022

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10:08 a.m. (CST), in the Werch Board Room, Woodridge Village Hall, 5 Village Drive, Woodridge, Illinois, Hon. Bill Foster [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Pedal to the Metal: Electric Vehicle Batteries and the Critical Minerals Supply Chain

Thursday, April 21, 2022
10:00 AM CT
Woodridge Village Board Room
5 Plaza Drive, Woodridge, Illinois

Purpose

The purpose of this hearing is to discuss the expected surge in demand for electric vehicle (EV) batteries over the next decade and consider the implications for critical minerals required in EV battery manufacturing, including cobalt, lithium, nickel, graphite, and manganese. The Members and witnesses will consider research opportunities to mitigate potential supply chain concerns, including new technologies for minerals extraction and processing, minerals recycling, and alternative battery chemistries. They will also explore strategies to maximize the research, development, and demonstration investments already being supported by the Department of Energy (DOE) pursuant to the Energy Act of 2020 and the Infrastructure Investment and Jobs Act (IIJA).

Witnesses

- **Mr. Nate Baguio,** Senior Vice President of Commercial Development, The Lion Electric Company
- **Mr. Chris Nevers,** Senior Director of Public Policy, Rivian
- **Dr. Venkat Srinivasan**, Deputy Director of the Joint Center for Energy Storage Research (JCESR) and Director of the Collaborative Center for Energy Storage Science (ACCESS), Argonne National Laboratory
- **Dr. Chibueze Amanchukwu,** Neubauer Family Assistant Professor of Molecular Engineering, University of Chicago

Key Questions

- What is the outlook and value proposition for the battery electric trucks and fleets?
- How is demand for EV batteries poised to grow, and what are the supply chain implications for EV battery components?
- What research topics (recycling, exploration, processing, critical material substitutes, alternative battery chemistries, etc.) hold promise for mitigating supply chain concerns associated with EV batteries?
- What are some key considerations for the federal government as it deploys IIJA funds and carries out authorizations in the Energy Act of 2020 related to EV battery research?
- What other activities should the federal government pursue to address this issue?

Background on EV sector growth and the battery mineral supply chain

Vehicle electrification is necessary to achieve net-zero emissions in the United States by 2050 and limit global warming to 1.5 degrees Celsius, as the Intergovernmental Panel on Climate Change says is required to avoid catastrophic climate conditions.

In 2019, global sales of electric cars totaled 2.2 million, about 2.5% of global car sales. In 2020, electric vehicles accounted for 4.1% of total car sales. In 2021, electric vehicle sales doubled again to 6.6 million, representing almost 9% of total car sales.[1] This aggressive growth is taking place in the United States as well as abroad. EV sales doubled in the United States from 308,000 in 2020 to 608,000 in 2021.[2] For context, internal combustion engine car sales grew by just 2.8% in the same period. S&P Global Platts Analytics projects that global EV sales will soar another 400% by 2030.[3]

The explosive commercial uptake of electric vehicles has been enabled in large part by the falling costs of batteries. Battery cells saw an 89% cost reduction in the last decade, falling from an average of $1,200/kWh in 2010 to $132/kWh in November 2021.[4]

But because the outlook for EV industry growth is so aggressive, demand for EV battery minerals is surging and will continue to increase. Raw material prices have already started to tick up. The global price of nickel had already doubled in the two years prior to Russia's invasion of Ukraine,[5] and lithium hydroxide prices increased 254% in 2021 alone.[6]

To be sure, supply chain bottlenecks associated with COVID-19 have yielded price affects for commodities and materials across many sectors of the global economy. But analysts attribute a large portion of surging minerals costs to the rapid increase in demand for EVs specifically. Accordingly, Bloomberg NEF projects that average battery pack prices could increase for the first time in 2022, up about 2% to an estimated $135/kWh.[7]

If EV battery mineral supplies are not diversified and/or increased and battery prices trend upwards as a result, it will be more difficult to achieve the Biden Administration's goal that 50% of vehicles sold in the United States be electric by 2030.[8]

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[1] https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales
[2] https://www.energy.gov/energysaver/articles/new-plug-electric-vehicle-sales-united-states-nearly-doubled-2020-2021
[3] https://www.spglobal.com/commodity-insights/en/market-insights/latest-news/energy-transition/021622-global-light-duty-ev-sales-to-rise-to-268-mil-by-2030-platts-analytics
[4] https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/
[5] https://www.wsj.com/articles/russia-can-hold-nickel-hostage-metals-mining-environment-china-class-domestic-electric-vehicles-11647287911
[6] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/121421-commodities-2022-global-lithium-market-to-remain-tight-into-2022
[7] https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/
[8] https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet-president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/

Critical Minerals in EV Batteries

The Energy Act of 2020 (30 U.S.C. 1606(a)) defines a critical mineral as "any mineral, element, substance, or materials designated as critical" by the Secretary of the Interior. The Department of Interior's list is based on a methodology developed in partnership with the White House Office of Science and Technology Policy's National Science and Technology Council (NSTC) Critical Minerals Subcommittee. The methodology is based in part on the relative insecurity of access for American consumers – e.g., how heavily production is weighted outside of the U.S. and whether there are single points of failure in the supply chain.[9] A "critical mineral" is also considered a "critical material" for purposes of dedicated R&D programs at the Department of Energy (DOE).[10]

The key critical minerals commonly used in EV batteries are lithium, cobalt, nickel, graphite, and manganese.[11] Note that battery EV motors often require a different set of critical minerals, specifically rare earth elements like neodymium.

- **Lithium:** BloombergNEF projects that without battery recycling, cumulative lithium demand will exceed known global reserves by 2050.[12]
- **Cobalt:** Less than 1% of known cobalt reserves are in the United States. The majority of global cobalt reserves are in the Democratic Republic of Congo, and a majority of cobalt processing is performed in China. The International Energy Administration expects global cobalt demand to double from 2020 to 2030, even if no additional policy supports for EVs are put in place.[13] The Federal Consortium on Advanced Batteries (FCAB) seeks to eliminate the need for cobalt in lithium-ion batteries by 2030.[14]
- **Nickel:** Less than 0.1% of known nickel reserves and manufacturing (processing) capacity are located in the United States. FCAB seeks to eliminate the need for nickel in lithium-ion batteries by 2030.[15]
- **Graphite:** Graphite comprises the majority of the battery anode. Virtually all of the global supply of processed graphite comes from China.[16]
- **Manganese:** Manganese is used in battery cathodes and supports energy density and reduced combustibility. Manganese demand may increase as it is substituted for nickel and cobalt. Around 80% of known manganese ore is located in South Africa.

The basic supply chain stages for EV battery minerals are as follows:

[9] https://www.govinfo.gov/content/pkg/FR-2021-11-09/pdf/FR-2021-11-09.pdf
[10] https://science.house.gov/imo/media/doc/Energy%20Act%20of%202020.pdf Section 7002(a)(2)
[11] https://www.govinfo.gov/content/pkg/FR-2022-02-24/pdf/2022-04027.pdf
[12] EVO 2021 (turtl.co)
[13] https://www.iea.org/data-and-statistics/charts/total-cobalt-demand-by-sector-and-scenario-2020-2040
[14] https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf
[15] Id
[16] https://electrek.co/2021/12/20/graphite-will-be-in-deficit-from-2022-heres-what-ev-battery-makers-need-to-do-to-secure-the-critical-mineral/

1. **Extraction and mining**: Some EV critical minerals are dissolved in surface or subsurface fluid, while others are found in clays and solid ores.
2. **Mineral processing:** a variety of processes, including smelting, electrowinning, crushing, separation, hydrometallurgy, comprise this stage. Processing allows for a pure form of the desired metal to be separated from the mined rock, fluid, or clay. The United States relies almost entirely on trade partners, particularly China, for minerals processing.
3. **Component Fabrication**. Once processed and refined, several EV battery minerals must be "doped" with other materials to make the active material used in battery applications. The active materials are then fabricated into recognizable battery components – the anodes, cathodes, and electrolytes. Currently the United States manufactures 0% of cathodes globally and only 10% of anodes, 2% of electrolyte solutions, and 6% of separators. China manufactures 65% of both anodes and electrolyte solutions, and 42% of cathodes.[17]
4. **Cell fabrication** – the anodes, cathodes, and electrolytes are packaged together into uniform electrochemical cells, each with a standardized power output. Tesla currently manufactures battery cells at its Gigafactory in Nevada. Thirteen new battery cell gigafactories are planned to come online in the United States by 2025.[18]
5. **Battery fabrication** – Cells are packaged together into recognizable battery modules, and then into packs, with electrical connections and any necessary cooling equipment. For example, a 2018 BMW i3 battery pack has eight modules, each made of 12 cells.[19]

Research Opportunities

New methods for extraction, processing, and refining: Innovators often seek to solve for environmental outcomes, such as reducing emissions or surface disturbance. For example:

- The ARPA-E MINER program is working on innovations to decrease energy required for comminution (breaking ore up into particles)
- DOE's American-Made Geothermal Lithium Extraction Prize seeks to develop technology strategies that enable direct lithium extraction from geothermal brines, which could avoid mining and additional surface disturbance.[20]
- In 2021, DOE's Advanced Manufacturing Office issued a $5.6 million grant to NOVONIX to support development of a synthetic graphite anode material.
- Talon Metals is planning an in situ carbon capture and storage project to sequester greenhouse gas emissions at its nickel-copper-cobalt mine in Minnesota.

Mineral Recycling: EV batteries last a decade or more. Researchers are planning now for both the chemistry and the logistics of how to extract and repurpose critical minerals from the relatively "young" battery stock in the current EV fleet. One significant engineering challenge is

[17] https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf Page 19
[18] https://www.energy.gov/eere/vehicles/articles/fotw-1217-december-20-2021-thirteen-new-electric-vehicle-battery-plants-are
[19] https://www.samsungsdi.com/column/all/detail/54344.html
[20] https://www.energy.gov/eere/articles/energy-department-announces-phase-1-semifinalists-geothermal-lithium-extraction-prize

designing an adaptable recycling schematic without knowing how the dominant battery chemistries may change in the coming decade. DOE's Vehicle Technologies Office supports an advanced battery recycling RD&D center at Argonne National Laboratory called ReCell.

Alternative battery chemistries: A number of research efforts are dedicated toward new chemistries that reduce or eliminate the cobalt and/or nickel components. New designs that increase the energy density of the cell will also help reduce critical mineral demand, as fewer cells could be required to achieve the same vehicle performance.

Federal Programs and Actions

Since 2011, DOE has funded the Critical Materials Institute, a multi-institution Energy Innovation Hub led by Ames National Laboratory, at about $25 million a year. CMI focused its research on diversifying material supplies, developing substitutes, improving reuse and recycling, and crosscutting research. CMI's last full year of funding was FY2021 and is in the process of closing out in FY2022.

In late 2012, DOE established the Joint Center for Energy Storage Research (JCESR), a separate Hub led by Argonne National Laboratory. In 2018 DOE renewed JCESR for another five-period with annual funding of $24 million per year.[21]

In the fall of 2020, four U.S. agencies – Energy, Defense, Commerce, and State – convened the Federal Consortium for Advanced Batteries (FCAB) to help build a domestic supply chain to manufacture batteries that can be used for all energy storage applications, including electric vehicles. In June 2021, FCAB released the *2021-2030 National Blueprint for Lithium Batteries*, which charts a strategy for discovering critical minerals alternatives and enabling recycling.[22]

The bipartisan Energy Act of 2020, signed into law in December 2020, directed DOE to undertake a critical material recycling and reuse R&D program for energy storage systems which includes a focus on such systems for EVs.[23]

On February 24, 2021, President Biden issued Executive Order 14017, *Securing America's Supply Chains,* which directed DOE to report on risks in the supply chain for EV batteries.[24]

The bipartisan Infrastructure Investment and Jobs Act was signed into law in November 2021.[25] It authorizes and appropriates over $7 billion in funding over five years to support a variety of EV battery minerals programs largely centered at DOE, including mapping of deposits and grants for research, development and demonstration of minerals processing, recycling, and alternatives. Among the funds appropriated are $75 million for the Critical Material Supply Chain Research Facility and $600 million for the Critical Material Innovation, Efficiency, and

[21] https://www.jcesr.org/jcesr-renewed-for-another-five-years/
[22] National Blueprint for Lithium Batteries 2021-2030 (energy.gov)
[23] https://science.house.gov/imo/media/doc/Energy%20Act%20of%202020.pdf
[24] https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/
[25] Public Law 117-58. https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.

Alternatives program, both of which were originally authorized in the Energy Act of 2020. It also expands the authorization of the Loan Programs at DOE to allow projects that increase the domestic sources of critical minerals, through production, processing, manufacturing, recycling, and/or fabrication.

On February 24, 2022, DOE announced a $44 million funding opportunity through the Advanced Research Projects Agency-Energy (ARPA-E) called Mining Innovations for Negative Emissions Resource Recovery (MINER). MINER aims to develop technologies that would enable greater domestic supplies of nickel, lithium, cobalt, and other critical elements.[26]

On March 31, 2022, President Biden invoked the Defense Production Act to boost U.S. production of battery minerals for electric vehicles.[27]

[26] https://arpa-e.energy.gov/news-and-media/press-releases/us-department-energy-announces-44-million-develop-technologies

[27] https://subscriber.politicopro.com/article/eenews/2022/03/30/biden-to-invoke-defense-production-act-on-battery-minerals-00021691

Chairman FOSTER. This hearing will come to order. Without objection, the Chair is authorized to declare recess at any time, and before I deliver my opening remarks, I wanted to note that today, the Committee is meeting both in person and virtually. I want to announce a couple of reminders to the Members about the conduct of this meeting. First, Members and staff who are attending in person may choose to be masked, but it is not a requirement. However, any individuals with symptoms, a positive test, or exposure to someone with COVID–19 should wear a mask while present. Members attending—who are attending virtually should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones, and so, please keep your microphones muted unless you are speaking. Finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the hearing.

Well, good morning to our witnesses and to our attendees. It's great to be here in a field hearing in Woodridge. I think the last time I was here was following the tornado, a somewhat less happy time here, and I'm really proud to be back here in more pleasant circumstances. I'm thrilled to be meeting on a transformational technology issue.

The United States has, at last, reached that story tipping point for affordable, high-quality, electric vehicles (EVs). The whole world is reaching for their wallets, and the 11th District of Illinois is answering the call. Rivian is, at this very moment, ramping up production of electric passenger and delivery trucks at its factory in Normal, and Lion Electric is readying for installation of production machinery at its electric bus factory in Joliet.

I should point out here that battery electric vehicles are not the only game in town, or more literally in this area, for low emission fleets. Hyzon Motors is manufacturing hydrogen fuel cells for commercial vehicles in Bolingbrook, and the internal combustion industry is not sitting still. Traditional trucks and buses have been diesel powered with fossil fuels, which means that they have a higher emissions profile for nitrous oxides and soot than gasoline-powered vehicles. Clearflame Engine Technologies in Geneva, in collaboration with Argonne, has developed low emission diesel engines that run at full thermodynamic efficiency, powered by low-carbon biofuels such as corn ethanol, which opens the door not only to low emissions long haul trucking, but tractors, harvesters, and a full line of farm equipment that run on fossil fuel free biofuels that the farm industry itself produces.

So, demand for low emission vehicles is booming, and our economy—local economy will reap the harvest.

And the clean truck and bus revolution is not just an opportunity for Illinois, but for a safer climate and cleaner air around the globe. An electric bus, on one hand, doesn't really emit anything at all during operations, and allows clean sources of electrical generation to contribute to decarbonization of the transportation sector. Electric fleets will enable massive improvements in urban air quality and help protect public health. Furthermore, over the life of the vehicle, the average EV has less than half of the carbon footprint per passenger mile than the equivalent internal combustion engine

(ICE) vehicle, and the environmental profile of EVs only gets better over time, as grid operators replace more and more fossil fuel plants with zero carbon alternatives. So, there is a lot to be excited about here.

Let us not forget that decades of dedicated research have led to this moment. It is no accident that the global transportation sector is changing. Cost-effective, lightweight, and long duration batteries that last more than a decade are the key, and they were developed over time by hardworking scientists and engineers with a very specific vision, many of them toiling up the street at Argonne National Lab. I am proud to count some of those friends as my constituents.

But now is not the time to stop innovating. On the Oversight Subcommittee for the House Science Committee, it is our responsibility to look into the technology concerns that could impede progress, and the supply chain for critical materials that go into an electric vehicle battery: lithium, cobalt, nickel, graphite, manganese, and others, may be an enormous technological and cost challenge.

The problem is so large that it has even become obvious to Elon Musk, who apparently spent a good fraction of yesterday's earnings call for Tesla complaining about the high cost of lithium.

Global demand for these critical minerals is surging, along with electric vehicle sales and projections from automakers. The numbers are simply eyepopping and because they have more cells in their products, Rivian, Lion Electric, and other companies that make big vehicles with big battery packs know better than anyone how mineral costs are affecting their bottom line.

Unfortunately, the United States is home to almost no mineral processing or midstream fabrication for batteries. China has invested billions in these steps of the supply chain, and as a result, they hold a lot of the cards right now. One value proposition of electric vehicles has always been their potential to loosen our dependence on a global commodity: oil. Oil prices are out of the U.S.'s control worldwide, so they create volatility in our economy and harm American families. Russia's war on Ukraine has brought to light the grave dangers of our geopolitical dependency on fossil fuels. The last thing we need is to exchange one form of geopolitical vulnerability for another. So, we need to focus on alternative battery chemistries, recycling strategies that can help keep mined minerals circulating in the economy, and new methods for extraction and processing that reduce environmental impacts.

I'm a technology optimist. I believe that we can engineer our way out of this problem, and the U.S. research enterprise has a lot more battery science breakthroughs up its sleeve. So many talented scientists, like Dr. Srinivasan and Dr. Amanchukwu—right? Yes. Thank you. Amanchukwu—are committed—have committed their professional lives to the battery mineral supply chain. We have exciting companies like Rivian and Lion Electric both contributing to that quest, and providing the demand pull for new innovations.

President Biden has set a goal for 2030 that half of the cars sold in the United States should be zero emissions and electric. I want to make sure that the Federal researchers are laser focused on that goal and deploying all available resources. I also want the Federal research enterprise to be thinking beyond 2030. So, I hope that our

witnesses today will be frank in their advice to the Committee and we—as we appreciate that decarbonizing the global transportation sector is a matter of urgency. So, I thank the witnesses for joining us.

[The prepared statement of Chairman Foster follows:]

Good morning to our witnesses and all our attendees. It's great to be here for a field hearing in Woodridge.

I'm thrilled to be meeting on a transformational technology issue. The United States has at last reached that storied "tipping point" for affordable, high-quality electric vehicles. The whole world is reaching for their wallets, and the 11th district of Illinois is answering the call. Rivian is at this very moment ramping up production of electric passenger and delivery trucks at its factory in Normal, and Lion Electric is readying for installation of production machinery at its electric bus factor in Joliet.

I should point out here that battery electric vehicles aren't the only game in town—literally, in this town—for low-emission fleets. Hyzon Motors is manufacturing hydrogen fuel cells for commercial vehicles in Bolingbrook. Clearflame Engine Technologies in Geneva has developed a truck powered by low-carbon biofuels. Demand for low-emission trucks and buses is booming, and our regional economy will reap the harvest.

But the clean truck and bus revolution is not just an opportunity for Illinois, but for a safer climate and cleaner air around the globe. Traditional trucks and buses tend to be diesel powered, which means they have a higher emissions profile for nitrous oxides and soot than gasoline-powered vehicles. An electric bus, on the other hand, doesn't emit anything at all. Electric fleets will enable massive improvements in urban air quality and help protect public health.

Furthermore, over the life of the vehicle, the average EV has less than half the carbon footprint per passenger mile than its equivalent internal combustion engine vehicle. And the environmental profile of EVs only gets better over time as grid operators replace more and more fossil plants with zero-carbon alternatives. There's a lot to be excited about.

Let us not forget that decades of dedicated research have led to this moment. It is no accident that the global transportation sector is changing. Cost-effective, lightweight, long-duration batteries that last more than a decade are the key. And they were developed over time by hardworking scientists and engineers with a very specific vision, many of them toiling up the street at Argonne National Lab. I'm proud to count some of these folks as my constituents.

But now is not the time to stop innovating. On the Oversight Subcommittee for the House Science Committee, it's our responsibility to look into technology concerns that could impede progress. And the supply chain for critical minerals that go into an electric vehicle battery—lithium, cobalt, nickel, graphite, manganese—may be an enormous technological challenge.

Global demand for these critical minerals is surging along with electric vehicle sales and projections from automakers. These numbers are simply eye-popping. And because they have more cells in their products, Rivian, Lion Electric and other companies that make big vehicles with big battery packs know better than anyone how much minerals costs affects their bottom line. Unfortunately, the United States is home to almost no mineral processing or midstream fabrication for batteries. China has invested billions in these steps of the supply chain and as a result, they hold a lot of the cards.

One value proposition of electric vehicles has always been their potential to loosen our dependence on a global commodity—oil. Oil prices are out of the U.S.'s control, and so they create volatility in our economy and harm American families. Russia's war on Ukraine has brought to light the grave dangers of our geopolitical dependency on fossil fuels. The last thing we want is to exchange one form of geopolitical vulnerability for another. So we need to focus on alternative battery chemistries, recycling strategies that can help keep mined minerals circulating in the economy, and new methods for extraction and processing that reduce environmental impacts.

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cused on that goal and deploying all available resources. I also want the federal research enterprise to be thinking beyond 2030.

I hope our witnesses today will be frank in their advice to the Committee, as we appreciate that decarbonizing the global transportation sector is a matter of urgency. I thank the witnesses for joining us.

Chairman FOSTER. So, if there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Globally, electric vehicle demand has tripled in just the last three years. It is expected to increase another five-fold by 2030. It's hard to fathom how rapidly the changes are coming in the transportation sector. We have to be ready to meet the booming demand for critical minerals that goes along with it. Unfortunately, the United States is responsible for almost none of the mineral processing and component fabrication steps in the EV supply chain. China and Russia have outsized control in these sectors, and that represents an economic threat to the United States. Now is the time for a robust, coordinated effort in the United States to develop new technologies for vehicle efficiency, minerals extraction and processing, alternative battery chemistries, and battery recycling and reuse. I am pleased the Subcommittee on Investigations & Oversight has taken up such an important topic for today's hearing.

It is impressive for me to see how this corner of Illinois has taken up the critical minerals challenge. Congress has been listening to experts like the witnesses before us today. And as a result, the last few months in Washington have seen a flurry of policy activity on the EV battery supply chain.

The *Energy Act of 2020*, which I led for the Committee on Science, Space, and Technology, directed DOE to undertake a research program on critical material recycling and reuse that promises to unlock exciting new innovations in the EV battery space.

In addition, the *Infrastructure Investment and Jobs Act* that President Biden signed into law this past December was an enormous leap forward. It includes at least a dozen sections that address battery materials. It has $3 billion in grant funding for EV minerals processing, and another $3.3 billion for EV battery recycling grants. It directs the U.S. Geological Survey to map potential critical mineral deposits under U.S. soil. It calls for the National Science Foundation and the Department of Energy to explore the use of artificial intelligence for geological exploration. It makes critical minerals projects eligible for loan guarantees from the Department of Energy. And earlier this week, DOE made its first such conditional commitment for a loan to Syrah Technologies to scale up production of graphite-based battery anode material.

The title of this hearing is "Pedal to the Metal" for a reason. We are not done yet. The Committee on Science, Space, and Technology has developed two other bills, the *DOE Science for the Future Act* and the *National Science Foundation for the Future Act,* which would both help advance early stage, fundamental research in battery science. Both of these bills passed the House as part of the *America COMPETES Act* earlier this year. I am leading the conference committee negotiations with the Senate, and Subcommittee Chairman Foster is a member of that committee as well. We intend to come to bipartisan agreements with the Senate that will help these become law this year. The *DOE Science for the Future Act* will authorize new advanced computing applications for chemistry and materials science. It will also authorize new money for the Electricity Storage Research Initiative, which will advance our ability to control, store, and convert electrical energy to chemical energy and vice versa.

I am proud of my colleagues in Congress for coming to the table on a bipartisan basis to tackle this critical technology challenge. And I hope our witnesses today will tell us how else we can help.

But I am even more proud of the researchers and innovators who are out there doing the work at American universities, national laboratories, and private companies. Texas is here for the challenge too. My hometown of Dallas has an exciting new technology start-up called Momentum. Momentum seeks to recycle lithium-ion batteries using foundational science that was developed at Oak Ridge National Laboratory. And they're hoping to have their first two battery recycling plants in operation by the end of this year. Down in Houston, a company called TexPower has developed a new cobalt-free cathode that they say can go head-to-head with today's battery chemistries, and they are cooperating with UT-Austin to develop new elec-

trolytes as well. These are the kinds of innovation stories we need to repeat over and over in the coming years.

I think we have a golden opportunity here. By redoubling our innovation efforts on EV minerals, we can not only help address the global climate crisis, but also regain economic leadership in the United States in the energy storage sector. I look forward to hearing from our witnesses about the best next steps for the federal research enterprise.

I yield back.

Chairman FOSTER. At this time, I'd like to introduce our witnesses.

Our first witness is Mr. Nate Baguio. Mr. Baguio is the Senior Vice President (VP) of Commercial Development at the Lion Electric Company. He has held positions at Lion as a leader in electric school bus deployments across North America, and works to provide a healthy breathing environment to students, drivers, and communities. Previously, Mr. Baguio has held leadership roles within various transit projects in Los Angeles County and in the school transportation sector.

Our next witness is Mr. Chris Nevers. Mr. Nevers is Senior Director of Public Policy at Rivian. He joined Rivian in February 2020 to help implement the policies needed to expand electrification and Rivian's role in creating a sustainable future. Prior to joining Rivian, Chris was the VP of Energy and Environment at the Alliance of Automobile Manufacturers and worked in EPA's (Environmental Protection Agency's) Office of Transportation and Air Quality, and held several roles at Chrysler. His work focuses on energy, the environment, and electrification.

Our third witness is Dr. Venkat Srinivasan. Dr. Srinivasan is the Director of the Argonne Collaborative Center for Energy Storage Sciences, or ACCESS, and Deputy Director of the Joint Center for Energy Storage Research, JCESR, at Argonne National Lab. His research develops continuum-based models for battery materials and combines them with experimental characterization to help design new materials, electrodes, and devices. Dr. Srinivasan previously served as the Acting Director of the Batteries for Advanced Transportation Technologies Program and as a department head and interim director at Lawrence Berkeley National Lab.

Our fourth witness is Dr. Chibueze Amanchukwu. Dr. Amanchukwu is a Neubauer Family Assistant Professor at the Pritzker School of Molecular Engineering at the University of Chicago. His research has focused broadly on sustainable energy technologies. His team is especially interested in understanding electrolyte behavior in a wide variety of electrochemical systems, such as batteries and electrocatalysis. His work has been recognized with an NSF (National Science Foundation) career award, an ECS (Electrochemical Society) Toyota Young Investigator Fellowship, and the 3M nontenured faculty award.

As our witnesses should know, you will each have five minutes for your spoken testimony. Your written testimony will be included in its entirety in the record for the hearing. When you have all completed your spoken testimony, we will begin with questions. Each Member will have five minutes to question the panel.

We will start with Mr. Baguio.

TESTIMONY OF MR. NATE BAGUIO,
SENIOR VICE PRESIDENT OF COMMERCIAL DEVELOPMENT,
THE LION ELECTRIC COMPANY

Mr. BAGUIO. Thank you, Chairman Foster, Congressman Casten, Ranking Member Obernolte, and esteemed Members of the Committee for inviting me to speak today.

As we meet here in the Land of Lincoln, it reminds me of something he once said. "You cannot escape the responsibility of tomorrow by evading it today." Today's discussion about this historic change in the way our great Nation's transportation system moves children, passengers, packages, materials, hauls waste, and important—imports and exports of goods through some of the world's busiest ports is as critical an issue as we face today.

With change comes opportunity, an opportunity to take a direct role in combatting climate change, creating healthy breathing environments in our communities and workplaces, reducing our dependence on overseas energy supplies, improving national security, and reducing the tax burden on our citizens.

Lion is a leading and dedicated to zero emission manufacturer of all electric medium- and heavy-duty vehicles, including school buses, urban delivery trucks, refuse trucks, and shuttle buses. Currently Lion has delivered nearly 600 vehicles in North America, and we are about to open the largest all-electric medium- and heavy-duty vehicle manufacturing site in the United States here in Illinois. At full production, this facility will produce 20,000 all-electric medium- and heavy-duty vehicles per year made by American workers. This factory is on schedule to be operational before the end of this year.

The transition to electric vehicles is already well underway, as EV car sales have more than doubled each of the past three years, even during the most significant health and supply chain crisis in our lifetime. Orders at the Lion Electric over a few years have grown by over 500 percent, with more expected to come with the Federal Clean School Bus Program opening in the coming days. This program will help communities most in need with $500 million in funding for electric school buses. Funding provided and recently signed into law in the *Infrastructure and Jobs Act* will add another $1 billion per year over the next five years for new, all-electric healthy school buses for children.

Modern electric school buses have been taking children to school since 2016, and have been outperforming their fossil fuel counterparts. On average, the cost to maintain an electric school bus is 80 percent less than a diesel bus, 60 percent less costly to fuel. The number of parts to replace, maintain, or fail in a diesel school bus versus an electric one are approximately ten to one. The lithium-ion batteries in these buses have performed well as well. At Lion, we are measuring less than 1/2 percent degradation available battery energy year over year from the robust use in wide-ranging climates.

It is important to note that these buses, although very different technology to diesel, meet or exceed all safety requirements under Federal law in each of the States in which they operate.

In order for original equipment manufacturers such as Lion to continue to provide and grow the availability to EVs in the U.S.

market, a stable supply chain needs to be present. The manufacturing capacity of vehicles is robust, as is the demand for these vehicles, but content continues to be based on volatile sources, even if the vehicles are actually built in America. It is critical to partner with favorable allies, such as Canada. The current Canadian Federal budget includes over $2 billion in research for the implementation of funding for critical mineral mining and processing as well.

Over 90 percent of the lithium-ion battery pack can be recycled or disposed of sustainably. The Recell Project at the Argonne National Lab is working to improve this as well. The goal is to reintroduce minerals and metals back into the supply chain, do it sustainably, and cost effectively. This continued research and recycling will be a key part of keeping up with the demand.

As demand on critical minerals and metals intensifies in the EV era, a program of encouraging responsible use of these valuable resources can effectively ease the burden on supply. The Federal Highway Administration just released results last month showing that Americans drive less than 40 miles per day. In very few instances do commuters need maximum range on their vehicle. The anxiety associated with range and the resulting strain on the battery supply chain can be offset with robust investment in charging infrastructure networks and public education.

Thank you for the opportunity to submit these brief comments to the Committee, and I invite any questions you may have for me.

Thank you.

[The prepared statement of Mr. Baguio follows:]

LION ELECTRIC

U.S. House Science, Technology, and Space Committee
Subcommittee on Investigations and Oversight

Written Testimony of Nate A. Baguio, Senior Vice President of Commercial Development

April 21, 2022

Thank you, Chairman Foster, Ranking Member Obernolte and esteemed members of the committee for inviting me to testify today. As we meet here in the *Land of Lincoln*, it reminds of something he once said,

"You cannot escape the responsibility of tomorrow by evading it today."

Today's discussion about this historic change in the way our great nation's transportation system moves children, passengers, packages, materials, hauls waste and imports and exports goods through some of world's busiest ports, is as critical an issue as we face today. With change comes opportunity. An opportunity to take a direct role in combating climate change, creating healthy breathing environments in our communities and workplaces, reducing our dependence on overseas energy supplies, improving national security and reducing the tax burden on our citizens.

My name is Nate Baguio and I serve as the Senior Vice President of Commercial Development for the Lion Electric Company. Lion is a leading and dedicated manufacturer of all-electric medium- and heavy-duty vehicles, including all-electric school buses, urban delivery trucks, and shuttle buses. Currently, Lion has delivered nearly 600 vehicles in North America, and we are opening the largest all-electric medium- and heavy-duty vehicle manufacturing site in the United States here in Illinois. At full-production, this facility will produce 20,000 all-electric medium- and heavy-duty vehicles per year made by American workers. This factory is on-schedule to be operational before the end of the year (2022).

Medium and Heavy-Duty Vehicle Demand and Performance

The transition to electric vehicles is already well underway as EV car sales have more than doubled each of the past three years, even during the most significant health and supply chain crisis of our lifetime. Orders at The Lion Electric Co. have grown by over 500% from this time last year with more expected upon the opening of the Federal Clean School Bus Program in the coming days. This program will help communities most in need with $500M in funding for electric school buses. Funding provided by the recently signed into law Investment in Infrastructure and Jobs Act that will add $1B per year over the next five years towards new, all-electric, healthy school buses for children.

Modern electric school buses have been taking children to school since 2016 and have been outperforming their fossil fuel counterparts. On average, the cost to maintain an electric school bus is 80% less than a diesel school bus and is 60% less costly to fuel. The number of parts to replace or maintain (or fail) in a diesel school bus vs. an electric are approximately 10-to-1.

The lithium-ion batteries in these buses have performed as well. At Lion, we are measuring less than 0.5% degradation of available battery energy year-over-year through robust use in wide-ranging climates.

It is important to note that these buses, although a very different technology, meet or exceed all of the safety requirements required under Federal law and each of the states in which they operate.

The direct operating benefits of medium and heavy duty all-electric vehicles only tell a portion of the story of reducing emissions in our communities.

According to the Environmental Defense Fund, removing tailpipe pollution from medium and heavy-duty vehicles by 2040 would:

- Prevent as many as 2,600 premature deaths and 140,000 lost workdays each year by 2040 and prevent as many as 57,000 premature deaths in total through 2050.
- Avoid 224 million metric tons of greenhouse gas (GHG) emissions every year by 2040 and eliminate more than 4.7 billion tons cumulatively by 2050.
- Significantly reduce ozone forming nitrogen oxides (NOx) pollution by more than 450,000 tons and harmful particulate pollution by nearly 9,000 tons every year by 2040.
- Provide our nation with up to $485 billion in health and environmental benefits alone because of pollution reductions.

Domestic and Partner Sources of Raw Materials

"China is the world's largest processor of copper, nickel, cobalt, lithium, and rare earth elements. It controls 75-percent of lithium-ion battery production, including 60 percent of the world's cathode production and 80 percent of the world's anode production – despite not having a geological advantage in the majority of these materials.", Abigail Wulf, Director for Center for Critical Minerals Strategy.

In order for original equipment manufacturers such as Lion Electric to continue to provide and grow the availability of EV's in the US market, a stable supply chain needs to be present. The manufacturing capacity of vehicles is robust as is the demand for these vehicles, but content continues to be based on volatile sources even if vehicles are built in America.

It is critical to partner with favorable allies such as Canada. The current Canadian federal budget includes over $2B in research and implementation funding for critical mineral mining and processing specifically for transportation. The transition to independence should consider opportunities not only in the US, but in Central and South America.

Recycle, Reuse and Use Responsibly

Over 90% of the lithium-ion battery pack can be recycled or disposed of sustainably. The ReCell project at the Argonne National Laboratory is working to improve the recycling process to separate and process more of the battery's content to be a useable source for future batteries. The goal is to reintroduce minerals and metals back into the supply chain, do it sustainably and cost effectively. This continued research and recycling will be a key part to keeping up with demand.

In some of our largest vehicles we have 508Kwh battery configurations that are designed to operate Class 8 trucks. In all of our vehicles these batteries can serve an additional life as stationary storage for solar or wind generated energy. This reuse of existing assets can reduce the demand for new batteries for less demanding uses. Depending on intended duty, this can potentially double the life of a battery

pack beyond its use in transportation. More research is warranted on second life viability as a mechanism to reduce strain on supply chain.

As the demand on critical minerals and metals intensifies in the EV era, a program of encouraging responsible use of these valuable resources can effectively ease the burden on supply. The Federal Highway Administration released new results last month showing that “on average” most Americans drive less than 40 miles per day. In very few instances do most commuters need maximum range on their vehicle. The anxiety associated with range and the resulting strain on battery supply chain can be offset with robust investment in charging infrastructure networks and public education.

Although lithium-ion chemistries are the most effective zero emission solutions for transportation today and for the years to come, new technologies will need to be developed for long range travel, aviation and transcontinental shipping. The United States will need to invest in less cobalt dependent chemistries and advance solid-state technology to achieve energy independence and meet climate goals to ensure future generations will have a liveable planet.

Thank you for the opportunity to submit these brief comments to the committee and I invite any questions you may have regarding the state of medium and heavy-duty electric transportation.

Nate Baguio has been working in the transportation industry for over 30 years. His career has taken him from behind the wheel of a school bus to launching the largest deployment of heavy-duty electric vehicles in North America.

Currently, he is working to electrify the transportation industry as Senior Vice President of Commercial Development for one of the nation's leading EV manufacturers, The Lion Electric Co. Since joining Lion in 2018, he has helped position Lion as the leader in electric school bus deployments across North America. Baguio is leading the Commercial Development team in warming markets in target states across the United States, advocating stakeholders and policy makers to fund more money into the EV industry, and helping Lion attain more of the available funding for both Lion's bus and truck lines. His work has contributed to Lion's exponential growth in the market and position as a policy leader in the EV industry.

In 1990, he started in the student transportation industry managing operations for Ryder Student Transportation Services. In this position, he had overall responsibility for the startup and deployment of school bus operations across the State of California. His time in operations was highlighted by the management of over 330 employees and the management of over 300 school bus routes for the Los Angeles Unified School District.

Baguio spent time working on various transit projects in Los Angeles County. He was part of the team that opened segment three of the Redline subway to 500,000 riders on opening weekend and worked to complete an $800-Million, 14-mile segment of light rail from Los Angeles to Pasadena (first segment of the Metro Gold Line). He was part of the team that designed and implemented a comprehensive safety project along the Metro Blue Line corridor in response to 16 fatalities in a single year. The first year of project implementation had an immediate impact with zero fatalities that year.

He returned to school transportation in 2005 as Senior Director of Business Development for First Student, Inc., the largest school bus operator in North America. In this role, he worked with school districts across the country to renew their contracted service or start new contracted school bus service. He led efforts that resulted in new contracted service across the U.S. and placed over 1,000 new school buses in service of various types and from most of the major OEMs for these new contracts.

Baguio is proud to not only provide a healthy breathing environment to students, drivers, technicians, and communities, but to also help educate the industry on the favorable economics of operating zero emission, electric medium and heavy-duty vehicles. He is determined to impact as many people across North America as possible to join in the fight for environmental justice and help create a cleaner, safer world.

Chairman FOSTER. Thank you, and next is Mr. Nevers.

TESTIMONY OF MR. CHRIS NEVERS,
SENIOR DIRECTOR OF PUBLIC POLICY, RIVIAN

Mr. NEVERS. Chairman Foster, Ranking Member Obernolte, Congressman Casten, and distinguished Members of the Subcommittee, thank you for the honor of appearing before you today for this important hearing to discuss ways for the United States to meet surging demand for battery electric vehicle.

My name is Chris Nevers, and I am the Senior Director of Public Policy for Rivian Automotive. We submitted written testimony to address some of the details of this hearing. I would like to use my oral testimony to touch on the high points and critical aspects surrounding electric vehicle batteries and the supply chain.

Rivian is a U.S.-based manufacturer of electric vehicles and chargers, with vehicle production in Illinois. Our mission is to keep the world adventurous forever; forever meaning sustainability, and sustainability in this case meaning the electrification of all transportation.

The key to accomplishing this mission are the three vehicles we now produce in Normal, Illinois: the R1T pickup, the R1S seven-seater SUV, and a commercial delivery van designed and engineered by Rivian in collaboration with Amazon. I'll note that the R1T is the first all-electric pickup in the U.S. and won the 2022 Motor Trend Truck of the Year.

In addition to producing electric vehicles, we have committed to both decarbonizing our business and helping to protect critical natural carbon sinks, complementary and necessary work that is required to address climate change.

We believe the United States must make transportation electrification a priority to address climate change, remain globally competitive, and strengthen our national economic security. We support congressional action to create targeted incentives, increase efficiency with funding and—funding deployment and permitting, and overcome unnecessary burdens to EV adoption such as State level dealer protection laws.

We also applaud Congress for its current action to strengthen our domestic semiconductor supply, and we encourage Congress to use its bipartisan work on semiconductors as a model for addressing our domestic mineral supply chain as well.

As our CEO recently said in a *Wall Street Journal* article, "Semiconductors are a small appetizer to what we are about to feel on battery cells over the next 2 decades." Although the demand for EVs is robust, market penetration will be limited by supply chain constraints.

The business and consumer value proposition of battery electric trucks and fleets are enormous, but battery prices have actually started to rise due to commodity pricing. Currently battery cell production capacity still represents perhaps less than 10 percent of what the market will need in the next 10 years.

To address the growing supply chain constraints, we need a whole of government approach to address surging critical mineral demand, starting with increasing and expediting Federal support for research into exploration, new extraction and processing meth-

ods, alternative battery chemistries, and recycling. The United States has the mineral resources and industrial capability to create a fully domestic battery EV supply chain, as well as world-leading environmental standards to ensure it is built and operated ethically and responsibly. There is also strong bipartisan support for increasing existing Federal investments, accelerating the deployment of funds, and removing unnecessary barriers to domestic EV adoption and battery development. These efforts will yield billions in new investment across America, create thousands of new jobs and ensure our supply chains continue to outpace consumer demand.

Thank you for your time, and I look forward to any questions you may have.

[The prepared statement of Mr. Nevers follows:]

RIVIAN

WRITTEN TESTIMONY BEFORE THE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT
U.S. HOUSE OF REPRESENTATIVES

ILLINOIS FIELD HEARING ENTITLED
"*Pedal to the Metal: Electric Vehicle Batteries and the Critical Minerals Supply Chain*"

CHRIS NEVERS
SENIOR DIRECTOR OF PUBLIC POLICY
RIVIAN AUTOMOTIVE, LLC

April 21, 2022

Chairman Foster, Ranking Member Obernolte and distinguished Members of the Subcommittee, thank you for the honor of appearing before you today for this important hearing to discuss ways for the United States to meet surging demand for battery electric vehicles (EVs).

My name is Chris Nevers and I am the Senior Director of Public Policy for Rivian Automotive, LLC.

We appreciate the unique setting for this field hearing to highlight how Illinois is leading the nation in securing our domestic EV and battery manufacturing supply chains.

Rivian is proud to manufacture its vehicles in Illinois. In 2017, the company acquired the former Mitsubishi production plant in the town of Normal. Originally slated to be torn down and repurposed for mixed use residential and commercial, Rivian has instead invested $2 billion into this facility and already created nearly 5,000 direct manufacturing jobs. We are now producing three models there: a light duty pick-up, a seven-seater SUV, and a commercial delivery van designed and engineered by Rivian in collaboration with Amazon, our first commercial customer. The R1T, our flagship vehicle, is the first all-electric pickup in the U.S. market and the 2022 MotorTrend Truck of the Year.

We remain focused on ramping up production at our plant in Normal, Illinois, and making significant investments in our next-generation vehicle platforms with bi-directional charging capability, improved cold weather efficiency, and new battery pack designs and chemistries.

Rivian's mission is to 'keep the world adventurous forever' and we've committed to both decarbonizing our business and helping to protect critical natural carbon sinks—complementary and necessary work that is required to address the climate crisis.

To address climate change, remain globally competitive and strengthen our national economic security, the United States must make transportation electrification a priority. Building a domestic battery and mineral supply chain will reduce costs and risks for companies like Rivian that have invested billions and created thousands of 21st Century jobs in America's heartland.

RIVIAN

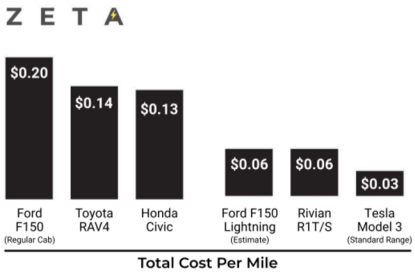
We support congressional action to create targeted incentives, increase efficiency with funding deployment and permitting, and overcome unnecessary barriers to EV adoption such as state-level dealer protection laws. We also applaud Congress for its current action to strengthen our domestic semiconductor supply, given the drag supply has had on Rivian's production outlook along with the rest of the industry. We encourage Congress to use its bipartisan work on semiconductors as a model for addressing our domestic mineral supply chain as well. As our CEO said in a recent Wall Street Journal article, "Semiconductors are a small appetizer to what we are about to feel on battery cells over the next two decades."[1]

Outlook and Value Proposition for Battery Electric Trucks and Fleets

Demand for battery electric trucks and fleets is surging. In Rivian's case, between individual R1T and R1S pre-orders and the Amazon fleet order—the largest commercial electric fleet order in history—we already have 180,000 deliveries to make as fast as we can.

The convergence of key trends, including shifting consumer preferences and targeted regulatory support, is contributing to the robust demand for EVs. Consumers are increasingly emphasizing sustainability in their purchasing decisions, encouraging businesses to develop sustainable solutions. Recognizing the environmental impact of increased deliveries, leading logistics and e-commerce companies are outpacing regulations in transforming their fleets. Companies such as Amazon, DHL, UPS, FedEx, and Ikea have publicly pledged to transition their delivery operations entirely to EVs to reach net zero carbon emissions in the near- to medium-term.

The business and consumer value propositions of battery electric trucks and fleets is enormous. According to Consumer Reports, the maintenance and repair savings over the lifetime of an EV compared to their gas-powered counterparts is about $4,600.[2] And according to a recent study by the Zero Emission Transportation Association (ZETA), driving an EV in 2022 is 3-5 times cheaper to drive per mile than gas-powered vehicles.[3]



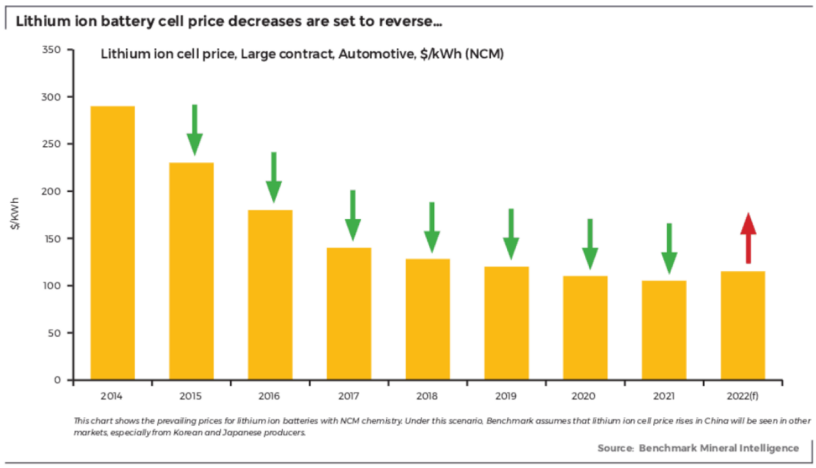
[1] Rivian CEO Warns of Looming Electric-Vehicle Battery Shortage, Wall Street Journal, April 18, 2022
[2] EVs Offer Big Savings Over Traditional Gas-Powered Cars, Consumer Reports, October 8, 2020.
[3] Comparing the Operating Costs of Electric Vehicles and Gas-Powered Vehicles, Zero Emission Transportation Association, March 14, 2022.

The crisis in Ukraine and its recent impact on gas prices at home is a powerful reminder of our nation's vulnerability to the volatile global oil market. According to AAA, gas prices have risen over 40 percent compared to last year.[4] Electrification will deliver significant cost savings for truck and fleet owners over the lifetime of their vehicles, and free us from the unpredictable price shocks associated with the global oil market.

EV Battery Demand and Supply Chain Implications

The battery is the most important component of an EV, and a vast majority of its supply chain—its raw materials, their processed derivatives, and the assembled cells themselves—still largely exists outside U.S. borders. While the outlook is positive and the value propositions are clear, these trajectories and adoption pathways may be compromised by lack of secure access to critical materials for battery manufacturing. To put this into perspective, all the world's current cell production capacity still represents perhaps less than 10 percent of what we will need in 10 years.[5]

The explosive global demand for EVs is already straining existing mineral supply chains. After falling nearly 90 percent over the past decade, from over $1,200 per kilowatt hour in 2010 to $132 in 2021,[6] battery prices are now on the rise.[7]



[4] Gas Prices, AAA, Accessed April 14, 2022.
[5] Rivian CEO Warns of Looming Electric-Vehicle Battery Shortage, Wall Street Journal, April 18, 2022
[6] Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite, Bloomberg New Energy Finance, November 30. 2021
[7] Lithium ion battery prices rise for first time in Gigafactory era, automakers in negotiations, Benchmark Mineral Intelligence, October 29, 2021

Our business depends on the continued supply of battery cells for our vehicles. A growth in popularity of EVs without a significant expansion in domestic battery cell production capacity could result in shortages, discouraging consumers and jeopardizing our national and economic security.

The United States has the mineral resources and industrial capability to create a fully domestic battery EV supply chain, as well as world-leading environmental standards to ensure it is built and operated ethically and responsibly. There is also strong bipartisan political support for increasing existing federal investments, accelerating the deployment of funds, and removing unnecessary barriers to domestic EV adoption and battery development. These efforts will yield billions in new investment across America, create thousands of new jobs, and ensure our supply chains continue outpacing consumer demand.

Research Topics to Mitigate Supply Chain Concerns

We need an "all of the above" approach to address surging critical minerals demand, starting with increasing and expedited federal support for research into exploration, new extraction methods, alternative battery chemistries, and recycling.

As a company that relies on the mining of critical minerals for our products, we recognize our business has an upstream impact on ecosystems. Some places should have a level of permanent protection and specifically prohibit or limit harmful extractive uses. Rivian has already taken proactive stances on land conservation issues, including supporting a moratorium on deep-sea mining and committing to exclude seabed metals from our supply chain. We also support recent Biden Administration action on the Tongass National Forest Roadless Rule and the "America the Beautiful" initiative to preserve 30 percent of US land and water by 2030.

The minerals mapping programs funded by the bipartisan Infrastructure Investment and Jobs Act of 2021 will help us identify places to be protected and those that can be developed responsibly. Federal research into new methods of mineral extraction like geothermal coproduction and mine waste reclamation could reduce extraction footprints, increase renewable energy production, and possibly even help rectify the legacy of 20th Century energy and mineral development.

Our current battery architecture consists of a lithium-ion nickel-cobalt-aluminum chemistry. We are exploring new and lower cost cell chemistries and intend to optimize each battery system to address different market segments and maximize battery life and performance. In March, we announced to shareholders that we will be developing a range of new battery packs including both high nickel and lithium iron phosphate ("LFP") chemistries to expand our available supply while reducing costs.

Given the paramount importance and impact of the battery system on vehicle range, performance, and price, federal research efforts into new battery cell chemistry development, solid-state batteries, module and pack engineering, software design, and raw material sourcing should increase and accelerate.

Key Considerations for Federal Research

Despite the gains made over the past ten years, electric vehicles still comprise less than 5% of all new car sales in the United States.[8] More must be done to promote American electrification. Rivian strongly supports the efforts by Congress promoting new transportation technologies in such recent bipartisan bills as the Energy Policy Act of 2020 and the Infrastructure Investment and Jobs Act of 2021. These bills put meaningful investment behind efforts to promote research and development in vehicle electrification, support new and improved methods of manufacturing for this technology, and address life cycle uses of electric vehicle batteries and their components.

The bipartisan Energy Policy Act of 2020 opened new funding gates for research into strengthening our nation's critical minerals supply chain and modernizing our electric grid.

This spirit of bipartisanship carried on with the passage of the Infrastructure Investment and Jobs Act of 2021 (IIJA), which in addition to fixing our nation's roads and bridges, also provided:

- over $6 billion in grants for battery materials processing, manufacturing and recycling,
- over a billion dollars for research into reclamation, recycling, and second-life applications to enhance grid infrastructure and reliability, and
- over half a billion dollars for new cross-agency mapping initiatives led by the US Geological Survey.[9]

We urge the Committee to do everything in its power in the coming years to ensure the appropriated funds for these efforts are deployed efficiently and equitably.

In addition to providing funding, the IIJA also directed federal land management agencies to look for ways to make their permitting processes run more efficiently. This must be done without compromising our nation's bedrock environmental laws and special places.

Other Activities the Federal Government Should Pursue

The federal government can achieve ambitious electrification objectives by empowering companies to ramp production – this includes accelerating EV testing procedures, expediting and streamlining federal EV fleet requirements, and quickly providing visas for skilled workers.

Given the national, economic, and climate security risks associated with the current global mineral supply chain, the federal government must take an "all-of-the-above" approach. Federal funding for research and development is crucial, but it can do more to open pathways for domestic manufacturers to move fast in scaling up production and securing supply chains.

- **Accelerate EV Adoption.** Greater domestic demand for EVs will drive innovation and support domestic manufacturers' efforts to onshore their supply chains. The federal consumer EV tax credit should be expanded without unnecessary limitations that hold

[8] Electric cars fend off supply challenges to more than double global sales, International Energy Agency, January 30, 2022

[9] Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act, Congressional Research Service, February 16, 2022

American manufacturers back from advancing the technology. The federal government could also create exceptions to state dealership protection laws,[10] which remain one of the biggest barriers to EV adoption in the US,[11] and avoid setting punitive EV fees.

- **Deploy federal funding in a more targeted and efficient manner.** The DOE Advanced Technology Vehicle Manufacturing loan program is well funded and expanded in scope, but it comes with administrative burdens that discourage potential applicants. The program can strike a better balance between holding loan holders accountable while also not being overly burdensome. Research grants should also be targeted to new technologies like batteries and not toward existing technology, like hybrid gasoline engines.

- **Streamline EV test procedures.** The EPA and DOT could further streamline test procedures initially created for internal combustion engine vehicles. This could include broader groupings of EVs certified in the same test group to more use of modeling in range and consumption testing.

- **Streamline federal fleet requirements for EVs.** To purchase vehicles directly from a manufacturer, federal agency fleet managers are directed to go through the General Services Administration (GSA). This process could be made more flexible, either through GSA or allowing agencies to purchase directly from a manufacturer.

- **Shore up allies and create new ones.** The United States must leverage its massive diplomatic and trade potential to further open global supply chains for both raw materials and talent. The International Development Finance Corporation could use its tools to help secure international mineral supply chains. The State Department can reinvigorate American diplomatic efforts in Asia, Africa and South America.

- **Accelerate visas for engineers who want to help build the EV industry here in the United States.** Rivian has brought together key talent from around the world, specializing in automotive and aerospace engineering, semiconductor design, consumer electronics, and cloud software. The federal government should increase efforts to help people with exceptional talent who want to build the future in America.

- **Update laws that regulate battery waste.** Congress can set standards while also maintaining flexibilities to suit the needs of a broad range of battery types, sizes, weights, applications, and users.

- **Embark on domestic mining reform.** This year marks the 150th anniversary of the 1872 Mining Law. It's time for an update. Conflict avoidance and permitting efficiency can be accomplished in a way that protects special places while still expanding our domestic resources and manufacturing capacity.

Thank you again for the opportunity to testify today. I look forward to your questions.

[10] How China Beat the US in Electric Vehicle Manufacturing, Issues in Science and Technology, Winter 2021.
[11] The Simplest Way to Sell More Electric Cars in America, The Atlantic, January 21, 2022.

Chris Nevers is the Senior Director of Public Policy at Rivian. Chris joined Rivian in February of 2020 to help implement the policies needed to expand electrification and to expand Rivian's role in creating a sustainable future. Prior to joining Rivian, Chris was the VP of Energy and Environment at the Alliance of Automobile Manufacturers, worked in EPA's Office of Transportation and Air Quality, and held several roles at Chrysler. Whether it be from the manufacturer, government, or trade association standpoint, Chris' focus has been on energy, the environment, and electrification.

Chairman FOSTER. Thank you, and next is Dr. Srinivasan.

**TESTIMONY OF DR. VENKAT SRINIVASAN,
DEPUTY DIRECTOR OF THE JOINT CENTER
FOR ENERGY STORAGE RESEARCH (JCESR)
AND DIRECTOR OF THE ARGONNE COLLABORATIVE CENTER
FOR ENERGY STORAGE SCIENCE (ACCESS),
ARGONNE NATIONAL LABORATORY**

Dr. SRINIVASAN. Chairman Foster, Congressman Casten, and distinguished Members of the Subcommittee, thank you for inviting me to testify at this important hearing.

My name is Venkat Srinivasan, and I am here representing Argonne National Lab. Let me start at the most important message I want to convey. I believe that we are at a unique moment in time where the United States can become a dominant force in energy storage technology. We have a once-in-a-lifetime opportunity to discover, manufacture, and commercialize next generation storage technologies to enable a carbon-free economy, ensure our energy security, create equitable jobs that benefit everyone, and position the U.S. as a leader in one of the most important technologies in the 21st century.

Let me elaborate. Over the last—past decade, the cost of lithium-ion batteries has decreased dramatically by an order of magnitude. This, in turn, has led to a surge in market demand with the increasing penetration of electric vehicles and grid connected storage. We expect the U.S. battery market to increase by a factor of 20 in the next decade. The growing demand for batteries has led to significant private capital flowing into the battery industry, and the Biden Administration and Congress have sent a clear signal on the need to transition the country to what is a carbon free economy. This is the good news.

The bad news is that our country does not have a secure supply to meet the growing demand. The supply gap stretches from minerals to materials to cells to packs. A 20-fold increase in cell manufacturing capacity is not a trivial task and takes time, money, and deep expertise, and the challenges get more acute as you move upstream where our country will continue to depend on complicated global supply chains for the battery materials and minerals, including cobalt, nickel, lithium, and graphite. These supply chains are subject to sudden dips in disruption like we have seen recently. Recycling should play an important role in bridging this operation gap, but it remains expensive and undeveloped. The gap is not just in supply chain, but also extends into the work force that is sorely missing to build this industry.

Beyond these operation issues, I want to emphasize that we will still have a technology gap in this space. While lithium-ion batteries have created a world where EVs are now not a distant dream but a reality, we still need significantly better batteries for economy-wide decarbonization.

Let me give you a couple of examples. Electrifying long haul trucks requires energy density twice that of lithium ion that we have today, and for electric aviation, it is even harder, requiring as much as three to five times the energy density. These dramatic

changes are not possible with incremental improvements to lithium-ion batteries.

In summary, we have a shot-term challenge. We know lithium ion works for many applications, but we need a secure supply chain. But we also have a long-term challenge. We need leapfrog technologies that can enable a sustainable, carbon-free future. To solve the shot-term challenges, we suggest these five parallel actions.

First, we should incentivize domestic mining, but do that with consideration for environmental impact, water, and energy use. Second, we should perform the R&D (research and development) to reduce the cost of recycling to enhance our supply, and do the kinds of research that the ReCell Center at Argonne is doing. Third, we should expand the research and development of substitutes for critical materials with emphasis on earth abundance and U.S. resources. Next, let us prioritize chemistry-agnostic R&D to ensure that the right battery is used for the right application, rather than relying on lithium-ion batteries for all the applications that are out there. Last, and the final one, we need to establish international collaborations so that we are working with our allies toward our common targets.

I want to emphasize that success in these five areas requires seamless interaction between fundamental science, applied research and development, and industrial production. Success will also require coupling the near-term actions that I've mentioned with a sort of complementary long-term solutions that can be the basis of a sustainable carbon-free economy. We need storage that enables deep decarbonization that is also inherently safe, uses earth-abundant materials, lasts many decades, and is completely recycled. Such chemistry is not achievable with incremental improvements in today's lithium-ion batteries. Rather, a basic science approach that brings new insights into battery storage, integrates the latest tools, such as artificial intelligence and machine learning, and enables actual discovery of novel materials, architectures, and systems will ensure long-term U.S. leadership in this technology.

The Federal Government has taken many bold steps in these directions. I want to call out all of DOE (Department of Energy) and all of government approach taken in programs of the Energy Storage Grand Challenge, and organizations like the Federal Consortium for Advanced Batteries (FCAB) that have really pushed the boundaries, and I want to call out the Office of Science with programs such as JCESR that have provided a pipeline of ideas that can lead to a diversified set of solutions.

I will close by noting that the United States has a long and rich history of innovation energy storage, with world-class expertise in fundamental and applied research. Our country continues to be a hotbed for entrepreneurship, with vibrant startup culture. However, we have struggled to translate these activities to a robust manufacturing base. We now have an opportunity to do this. We should seize this moment to become the world's leader in the most important technologies of the 21st century.

Thank you again for giving me the time to speak at this meeting. I will be happy to answer any questions that you might have.

[The prepared statement of Dr. Srinivasan follows:]

Written testimony of
Venkat Srinivasan
Argonne National Lab

Before the
House Committee on Science, Space, and Technology
For the hearing titled
Pedal to the Metal: Electric Vehicle Batteries and the Critical Minerals Supply Chain

April 21, 2022

Chairman Foster and distinguished members of the subcommittee, thank you for inviting me to testify at this important hearing. My name is Venkat Srinivasan and in my roles at Argonne National Laboratory, I serve as the Director of the Argonne Collaborative Center for Energy Storage Science, or ACCESS, and as the Deputy Director of the Joint Center for Energy Storage research, or JCESR. I'm honored to represent our nation's 17 national laboratories, many of which are hard at work addressing the topic of our conversation today.

We are at a unique moment in time where the United States can become a dominant force in energy storage technology. We have a once-in-a-lifetime opportunity to seize the moment to discover, manufacture, and commercialize future storage technologies to enable a carbon-free economy, ensure our energy security, create equitable jobs that benefit everyone, and position the U.S. as a leader in one of the most important technologies of the 21st century.

This is a historic moment for the U.S. energy storage ecosystem:

After a century of powering cars with gasoline and producing electricity using coal, we are at the cusp of a revolution in the energy sector. At the heart of this transition is energy storage, long considered the "holy grail" for decarbonization of transportation and the electric grid. Robust research and development, coupled with innovations in manufacturing, have led to an order of magnitude cost reduction for lithium-ion (Li-ion) batteries in the last decade. This dramatic change has led to light duty electric vehicles (EV) achieving cost and range parity with internal combustion engine (ICE) vehicles. In addition, in regions with high electricity costs, such as California and Hawaii, Li-ion batteries, coupled with solar panels, provide electricity at lower cost compared to fossil-fuel generation.

Significant reduction in battery costs have led to three trends which, combined, are poised to alter the landscape for batteries in the U.S. First, the market for EVs has grown tremendously in the last five years. In 2021, EVs accounted for 9% of global car market (6.6 MM), more than tripling their market share compared to 2019.[1] With recent announcements from practically

[1] https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales. Accessed: April 9, 2022

every major auto manufacturer for expanding their EV offerings, the global electric vehicle market is expected to exceed 30 MM cars by 2030.[2] Estimates suggest that the U.S. Li-ion battery market to power these EVs will exceed one Terra-watt-hour (TWh) a year by 2030[3].

In addition, increasing penetration of renewable resources on the electric grid further drives the market for Li-ion batteries, especially for energy storage in the 4-6h duration. The actual size of the storage market for the grid is dependent on possible build out of interstate transmission (more transmission serves to buffer intermittency of renewables and thereby decreasing the dependance on distributed storage).[4] Despite this ambiguity, achieving the administration's 2035 100 percent clean electricity target will require an additional 0.5-1 TWh/year of Li-ion battery manufacturing capacity in the U.S. Between EVs and grid storage, the market for Li-ion batteries in the U.S. is expected to increase by a factor of twenty to thirty in the next decade.

The second trend is access to vast private capital aimed at commercializing storage technologies. Companies in the "green" sector raised $90B in 2021, many in the field of battery technology and EVs.[5] Through mechanisms such as mergers with Special Purpose Acquisition Companies (SPACs), battery startups have raised hundreds of millions to billions of dollars' worth of capital, enabling them to transition from small-scale R&D into large-scale manufacturing. Considering the large capital costs for battery materials and cell manufacturing facilities, access to capital is a prerequisite to ensuing a robust industrial base. The last two years has seen this much-needed infusion of capital into batteries.

Finally, the Biden administration has sent a clear signal on the need to transition the country toward a carbon-free economy. This includes the goal for half of all new passenger vehicle sales to be EVs by 2030, converting the electric sector to net-zero by 2035, and transitioning the economy to net-zero by 2050. Further, the Bipartisan Infrastructure Law (BIL) allocates nearly $7B to strengthen the U.S. battery supply chain. This level of investment has provided capital markets and battery companies with the assurance to expand on their investments, further reinforcing the positive momentum.

The convergence of these factors has resulted in a once-in-a-lifetime opportunity for the U.S. to become the dominant player in this critical technology. The U.S. has long been a powerhouse in energy storage research, however, in the 1990's lost manufacturing to Asian countries. We now have an opportunity to reverse that trend and bring battery manufacturing back to the U.S.

However, the U.S. has a significant challenge in meeting the expected demand:

While the expected TWh/year market for Li-ion batteries presents an historic opportunity, the U.S. manufacturing capacity is currently around 59 GWh/year, requiring rapid capacity building, in the order of twenty-five "gigafactories" within the next decade. In the last year, automakers

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[2] National Blueprint for Lithium Batteries, June 2021.
[3] 1 TWh can power ~10M EVs, each with ~350 mile driving range
[4] Brown & Botterud, Joule 5, 1–20, January 20, 2021
[5] https://www.wsj.com/articles/green-startups-flush-with-cash-face-pressure-to-make-climate-advances-11647682202?st=pvemxctfo8de1ew&reflink=desktopwebshare_permalink Accessed: April 9, 2022

have partnered with large battery manufacturers to break ground on several gigafactories, which is a much-needed development but still far too small to meet the expected demand.

Every Li-ion battery consists of three active components: the anode, typically graphite; the cathode, typically based on a nickel, cobalt, and manganese-based oxide (NMC); and an electrolyte, typically a salt of lithium in an inorganic solvent. In addition, the battery also has inactive components: a polymer separator, and copper and aluminum current collectors. These components are carefully assembled into cells that are packaged to meet the energy, power, life, safety, and cost metrics for use in different applications. The critical role of the battery in the device necessitates a level of sophistication and automation in manufacturing that is not easily achieved. Building the manufacturing capacity requires deep expertise, complex supply chains, and access to vast capital (A typical gigafactory can cost $2-3B).

Even more urgent is the need to build facilities to synthesize the battery materials that are the core of these devices. These materials need to be processed to achieve specific properties. For example, battery cathodes require synthesis with exquisite control over their structure, morphology, size, and shape to ensure that they provide superior performance and life. This requires sophisticated material synthesis expertise. While the U.S. has small-scale cathode, electrolyte, and anode material manufacturing, these facilities will need to scale significantly to meet the expected demand.

Further upstream, metal salt precursors are needed to synthesis active materials. For example, the NMC cathode requires sulfate salts of the transition metals along with a hydroxide salt of lithium. The U.S. does not have facilities that refine and synthesize these precursors. Investments must be made to build these facilities at the scale needed to feed the gigafactories.

Finally, the domestic supply of minerals that go into the battery, especially nickel and cobalt, are not sufficient. As an example, the reserves of nickel in the U.S. only provide enough materials for 167 GWh: an order of magnitude less than the yearly requirement. Cobalt, another critical mineral, has more availability in the U.S. than nickel (U.S. reserves could satisfy up to 700 GWh capacity), but significantly lower than long-term needs.[6] While the U.S. has recently explored unconventional sources, such as the geothermal mines in the Salton Sea in California for lithium, developing these sources requires significant investments and time, including for permitting and environmental clearances.

The lack of upstream supply means that the US will remain dependent on foreign sources of minerals, refined materials, and battery materials for the foreseeable future, unless we act soon. Cobalt and graphite are especially important considering the concentration of these resources in specific geographic regions (50% cobalt reserves are in the Democratic Republic of Congo while 70% of natural graphite is in China).[7] Nickel, while more geographically prevalent, including in the Philippines, Canada, and Indonesia, has seen recent challenges due to the war in Ukraine and the subsequent price hikes in the London Metals Exchange.

Recycling could well hold the key to building a secure materials supply. However, today, the U.S. does not have any appreciable recycling capacity. Further, collection processes for Li-ion

[6] National Blueprint for Lithium Batteries, June 2021.
[7] Joule 1.2 (2017): 229-243

batteries already in the market, including various consumer devices, remains inadequate. While recycling is cost effective for cobalt and nickel, the volume of spent batteries is too small to meet the growing demand. Recycling can and should be part of the solution but will remain a small fraction of what the demand will be for battery critical materials in the near term.

Mining is also reputationally-challenged due to a lack of environmental social and governance (ESG) considerations in much of the world. ESG consideration will need to be front and center as the U.S. develops domestic resources for battery critical materials. Further, the environmental impact requires the active support of affected communities and a pathway to ensure that the benefits of the transition to clean energy reach underserved communities that have been most affected by these actions.

Last, but not least, the workforce needed to enable this transition is a significant challenge that requires careful consideration. The battery community, spanning academia, National Labs, and industry, is facing an unprecedented shortfall in a skilled workforce. This shortfall is across skill levels and could derail the opportunity to grow this industry.

In summary, the U.S. has a significant supply chain challenge for meeting the expected demand for lithium batteries. Bridging the gap requires a comprehensive strategy.

Deep decarbonization requires next generation batteries, beyond today's Li-ion:

While advanced Li-ion batteries have had an outsized impact on EVs and short-duration (<4h) stationary storage, some challenges remain, including further reduction in cost, faster charging, and increased lifetimes. Achieving these targets requires new chemistry solutions, and new materials. Recent trends, including the use of silicon as the anode and solid-state batteries that use lithium metal as the anode, suggest that a leapfrog in technology is imminent. In the R&D pipeline, chemistries that can meet the EV cost target of $60-80/kWh, such as lithium-sulfur batteries, which have higher energy density and reduced costs, are being examined. While these changes don't eliminate the critical materials dependence completely, they lighten the burden by diversifying the supply. Beyond light duty passenger cars, electrifying long haul trucks requires almost twice the energy density of today's Li-ion battery. The challenges become more acute for electric aviation with targets that can be more than three to five times what is possible today.[8] Decarbonizing these sectors will require new storage chemistries.

While Li-ion batteries have become the preferred solution for solar-connected storage, the chemistry becomes less attractive for longer storage times. With increasing renewable penetration, past 60% of total electricity generation, long duration storage, ranging from multi-day to seasonal, becomes more important. The cost targets for these applications are significantly more aggressive compared to short-duration storage. For example, the recently announced Department of Energy earth shot on long duration storage calls for a 90% reduction in cost for storage times greater than 10h.[9] Further, grid installations require lifetimes of multiple

[8] https://www.anl.gov/article/white-paper-assessment-of-the-rd-needs-for-electric-aviation Accessed: April 9 2021
[9] https://www.energy.gov/eere/long-duration-storage-shot Accessed: April 9 2021

decades, rather than the 8-year lifetime for EVs. Achieving this target will require new storage technologies.

While the technology targets for deep decarbonization are challenging, it also presents an opportunity to discover the battery of the future that is made from earth abundant materials using low energy routes. Such a battery will not be found by tweaking today's systems; rather a fundamental science-based approach is needed that can revolutionize our ability to harness the capabilities of materials and chemistries to store electrons. Discovering such a battery will allow the U.S. to leapfrog existing batterie technologies to enable a carbon-free economy, maintain US scientific leadership, establish manufacturing prowess, and create the jobs of the future.

Addressing the supply chain gap requires a multipronged strategy:

The significant challenges presented above require a comprehensive approach that embraces two aspects (i) a near-term strategy to build the domestic supply chain for lithium batteries and (ii) ensuring that long-term sustainable technologically advanced solutions are discovered that can enable economy-wide decarbonization.

To achieve the near-term objectives, we suggest the following five approaches:

1. **Incentivize domestic mining and refining of battery critical materials**: The country should take advantage of the resources in our lands and ensure that they are extracted with consideration for environmental impact, water, and energy use. Incentivizing the discovery and development of novel, cost effective, low-energy routes is critical for this endeavor.
2. **Encourage the development of low-cost recycling processes**: Battery recycling, worldwide, is still in its infancy. Developing cost effective recycling, not just for critical elements, but for all the components in the battery, will allow the U.S. to develop intellectual property and be leaders in this emerging industry.
3. **Spur research into the development of substitutes**: Recent efforts have led to cobalt content decreasing from 30% to less than 10%. Further decreasing, and ultimately eliminating cobalt, is critical. In addition, consideration should be given to minimizing and removing nickel. Discovering new chemistries with earth abundant materials, like sodium, manganese and iron, should continue to be a focus of research.
4. **Prioritize chemistry-agnostic R&D to ensure that the right battery is used for the right application**: Transportation beyond light duty vehicles, and long duration storage beyond 10h, require storage beyond Li-ion batteries. Alternates such as flow batteries, aqueous batteries, thermal storge, and chemical storage, provide alternative pathways that can help diversify and decrease dependence on Li-ion materials. Innovation in these areas, for example at the Joint Center for Energy Storage Research (JCESR), provide an opportunity for generating intellectual property while encouraging material diversity.[10] An example is the early focus in JCESR on long duration storage that led to the creation of Form Energy, a Massachusetts startup focused on low-cost multi-day storage.

[10] Proceedings of the National Academy of Sciences 117.23 (2020): 12550-12557

5. **Establish international collaborations**: The geographical location of Li-ion raw materials is such that the U.S. needs partners to build its supply chain. Countries such as Canada, and Australia, and regions such as Southern Africa have access to these materials. Further, R&D collaborations with the EU and Great Britain could accelerate the development of sustainable chemistries and recycling technologies.

Success in these five areas require seamless interaction between fundamental science, applied research and development, and industrial production. Accelerating the deployment of new materials requires such close interactions, pulling together the strengths of the various stakeholders.

The near-term objectives listed above should be complemented with a long-term view of developing solutions that will be the basis for a sustainable, carbon-free economy. Deep decarbonization requires storage with significantly higher energy density, lower cost, incredible safety, complete circularity, multidecadal lifetimes, utilizing earth abundant materials. Such chemistries are not achievable with incremental improvements to today's Li-ion batteries. Rather, a basic science approach that brings new insights into energy storage, integrates the latest tools such as artificial intelligence and machine learning, and enables accelerated discovery of novel materials, architectures, and systems will ensure long-term U.S. leadership in this technology.

Parallel with the technology strategy, a complementary workforce strategy is needed to ensure that the necessary skills are part of the education system. The workforce strategy will need to anticipate of the evolution of the technology and requires a holistic approach that links the technology leaders with educators in community colleges, trade schools, 4-year universities etc.

The federal government has taken bold steps to address the challenge:

Over the last 4 years, the Department of Energy (DOE) has identified the critical challenge related to the battery supply chain and has taken strategic steps to bridge the gap. The complex nature of batteries requires strong and sustained support across multiple technology readiness levels. Fundamental science allows new learnings and leads to discovery of new materials, architectures, and devices. This in turn enables application-driven R&D to translate the learning toward real-world use, aided by industries pulling innovation from the lab to large scale production. Innovation is also not linear, often requiring new scientific knowledge at all stages of technology development.

DOE-Office of Energy Efficiency and Renewable Energy recognized that the challenge required an all-of-government approach and helped launch the Federal Consortium for Advanced Batteries (FCAB).[11] FCAB brings together fourteen federal agencies, including Energy, Defense, State, and Commerce, and is charged with developing a comprehensive strategy to address the supply chain

[11] https://www.energy.gov/eere/vehicles/federal-consortium-advanced-batteries-fcab. Accessed: April 9, 2021

gap. FCAB's strategy for the country is captured in the National Blueprint for Lithium Batteries and the 100-day supply chain report, both released last year.

Further, DOE and FCAB have partnered with Argonne National Laboratory to establish the Li-Bridge Alliance, a unique, national public-private partnership aimed at bridging the battery supply chain gap. Li-Bridge brings together the DOE National Lab system and FCAB, representing the public side of the partnership three U.S.-based convenor organizations: NAATBatt International, New York Battery and Energy Storage Technology Consortium (NY-BEST), and New Energy Nexus, representing the private side of the partnership. Li-Bridge is working with U.S. battery companies to discuss the gaps in supply chain, sources of raw materials, challenges with U.S. manufacturing, recycling issues, role of government, approaches for developing a domestic workforce, and role of new technologies.

DOE's Office of Electricity, working closely with Office of Science and EERE, has established the Energy Storage Grand Challenge (ESGC), a comprehensive effort to accelerate the development, commercialization, and utilization of next-generation energy storage technologies.[12] ESGC has released a comprehensive roadmap articulating multiple use cases for storage and a holistic approach spanning bi-directional storage, chemical and thermal storage, and flexible generation and loads. Under the leadership of the ESGC, DOE recently announced the long duration storage shot, as mentioned previously. The holistic focus of ESGC is critical in ensuring that a diverse set of solutions are implemented to meet the market demand.

DOE-Office of Science has long had research efforts aimed at discovering the next generation battery chemistries under JCESR and the Energy Frontier Research Centers (EFRCs). In these programs, fundamental materials and chemistry research is complemented with the use of the synchrotron light sources, such as the Advanced Photon Source at Argonne, to understand the changes in battery materials *in situ* during their operation. Further, the extensive use of supercomputing facilities, combined with advances in artificial intelligence and machine learning, has accelerated the discovery of new battery materials with revolutionary performance. Recently, the office has put out calls for proposals aimed at clean energy solutions, including storage, consistent with the Storage Shot. These efforts provide the pipeline of innovation that can enable sustainable solutions for deep decarbonization of the economy.

Finally, the recently announced funding for batteries as part of the Bipartisan Infrastructure Law provides a much-needed shot in the arm for building the supply chain in the U.S. and ensure that a secure, sustainable battery industry can be developed in the next decade.

Summary and conclusion:

The United States has a long and rich history of innovation in energy storage with world-class expertise in fundamental and applied sciences. Further the U.S. continues to be a hotbed for nucleating innovative startups with a well-established pipeline to move technologies from the lab to the market. However, the U.S. has struggled to translate these activities into a robust

[12] https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge Accessed: April 9, 2021

manufacturing base. We now have an opportunity to reverse this trend, buoyed by the tremendous market demand expected in the next decade. But the lack of a manufacturing base and the necessary battery supply chain can be a serious impediment to translate this opportunity into jobs and economic growth. A holistic multipronged strategy is necessary to achieve the vision of a secure domestic battery industry that is the linchpin for decarbonizing the economy. We should seize this moment and support this holistic strategy to ensure that US becomes a leader in this critical technology.

Thank you for the opportunity to address you this morning on this important topic. I would be pleased to answer any questions that you might have.

Venkat Srinivasan is the director of the Argonne Collaborative Center for Energy Storage Science (ACCESS) and deputy director of the Joint Center for Energy Storage Research (JCESR).

ACCESS provides the vision and coordinates the energy storage programs at Argonne and serves as a point of entry for industry to take advantage of the unique capabilities and facilities at Argonne to solve their problems in energy storage. JCESR is a national program led by Argonne that focuses on next-generation energy storage research that goes beyond lithium-ion technology.

He is a former staff scientist at Lawrence Berkeley National Laboratory. His research interest is in developing next-generation batteries for use in vehicle and grid applications, among other things. Dr. Srinivasan and his research group develop continuum-based models for battery materials and combine them with experimental characterization to help design new materials, electrodes, and devices.

In addition to his research, Dr. Srinivasan is interested in moving technologies to market and has been exploring ways to develop an ecosystem, focused on batteries, to accelerate technology commercialization. In this role, Dr. Srinivasan conceived the idea of CalCharge, a one-of-a-kind public-private partnership in energy storage.

Dr. Srinivasan has previously served as the technical manager of the Batteries for Advanced Transportation Technologies (BATT) Program, as the acting director of the BATT program, as department head of the Energy Storage and Distributed Resources (ESDR) department at LBNL, and the interim director of the ESDR Division at LBNL. Dr. Srinivasan joined the scientific staff at LBNL in 2003 after postdoctoral studies at the University of California, Berkeley and Pennsylvania State University. He received his PhD from the University of South Carolina in 2000.

He is also the author of a popular battery blog titled, "This Week in Batteries."

Chairman FOSTER. Thank you.
Next is Dr. Amanchukwu.

TESTIMONY OF DR. CHIBUEZE AMANCHUKWU,
NEUBAUER FAMILY ASSISTANT PROFESSOR
OF MOLECULAR ENGINEERING, UNIVERSITY OF CHICAGO

Dr. AMANCHUKWU. Chairman Foster, Honorable Casten, and all distinguished Members of the Committee, thank you for the invitation.

I am an assistant professor at the Pritzker School of Molecular Engineering at the University of Chicago, and I am honored to join the Committee today at this pivotal moment in the U.S. energy industry, a moment that could define the next century.

The renewable energy transition is already upon us, but we can learn from the past with other energy transitions. The advent of the internal combustion engine led to the rise of gasoline as a fuel source. Crude oil was easy to source in the U.S.; however, as car manufacturing and deployment soared, the U.S. became an oil importer. Dependence on foreign oil led to the oil shocks of the 1970's that made the U.S. vulnerable. Fortunately, innovation in drilling practices, such as horizontal drilling and proliferation of natural gas set the U.S. on its path as the world's top oil exporter today.

From this history, it is important to emphasize that innovation, rather than diversification alone, played a primary role in regaining U.S.'s energy independence. This history provides a lens with which to view the challenges that will arise in the current energy transition.

Innovation focused on alternative battery chemistries beyond current lithium-ion batteries is the ultimate disruptor and path to mitigating supply chain challenges and making the U.S. energy independent. Batteries are complex devices, and can be broken down into three primary components: the anode, the electrolytes, and the cathode. Many of the current supply chain challenges can be tied to the cathode. Promising short-term research efforts have focused on reducing the cobalt content and increasing the nickel content in these batteries.

My research group at the University of Chicago has invested heavily in designing new electrolytes that can allow these next-generation cathodes to be used. However, nickel will become an even more critical material; hence, this strategy works only for the short-term.

Promising long-term research efforts focus on batteries that do not exist today. My research group is working on some of these new chemistries. Alternatives that use lithium metal as the anode have been termed the Holy Grail because they can double the energy that can be stored. Some battery chemistries completely eliminate the use of lithium, such as sodium ion, fluoride ion, calcium and dual ion batteries. However, these battery chemistries are plagued by lack of suitable electrolytes and many other challenges, and suffer from poor understanding of the fundamental mechanism. That is why continued and increased funding appropriation for basic and fundamental research through the Department of Energy's Office of Science and the National Science Foundation is key.

From the discovery of lithium cobalt oxide by University of Chicago alumnus John Goodenough, to the development of lithium nickel manganese cobalt oxide NMCs at Argonne, U.S.-based and U.S.-led innovation in the lithium-ion battery chemistry are what led to the revolution in energy storage. However, America lagged in translating these discoveries to the marketplace and fell behind its counterparts in Europe and Asia.

The recently enacted *Bipartisan Infrastructure Bill* acknowledges these challenges and provides funding and incentives to U.S. companies. Even greater efforts would be needed to translate future battery discoveries to American industry. Significant effort must be placed on training the talent and U.S. work force that will develop next generation batteries, build those batteries, and manufacture electric vehicles here in the U.S. This is an area where universities have historically shone. Training women and under-represented minorities in battery science and electrochemistry is important and under-represented minorities in battery science and electric chemistry is important to ensure that all segments of U.S. society benefit from the energy transition. A curriculum that was heavily dominated by the thermochemistry of the past century will need to transition to electrochemistry for the next century.

To summarize, as the U.S. ramps up deployment of electric vehicles and battery manufacturing, it is important that the U.S. continue to invest in fundamental research to develop alternative battery chemistries with properties that surpass that of current lithium ion. This alternative battery chemistry strategy is the pathway for the U.S. to regain its perch as the leader in battery technology and lead the world as it transitions. In the past, the U.S. innovated in batteries but did not manufacture. Now, we need to manufacture and continue innovating.

Thank you.

[The prepared statement of Dr. Amanchukwu follows:]

Written testimony of

Chibueze Amanchukwu

Assistant Professor

Pritzker School of Molecular Engineering

University of Chicago

Before the House Committee on Science, Space, and Technology

For the hearing titled

Pedal to the Metal: Electric Vehicle Batteries and the Critical Minerals Supply Chain

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Representative Foster, Representative Casten, and all distinguished members of the committee, thank you for the invitation to join the hearing today. I am an assistant professor in the Pritzker School of Molecular Engineering at the University of Chicago. I am honored to join the committee at this pivotal moment in the U.S. energy history, a moment that could define the next century.

Summary

The renewable energy revolution is already upon us. As the U.S. ramps up deployment of electric vehicles (EVs), EV charging infrastructure, and battery manufacturing, the battery technology most ready is the lithium-ion battery. However, as these batteries are scaled up in GWh capacities, supply chain deficiencies in cobalt, nickel, graphite, and lithium will impede the ability of the U.S. to catch up to its counterparts in Europe and Asia. The U.S. must become self-sufficient and invest not only in the production of electric vehicles, but at upstream and downstream points in the supply chain. *While continued deployment is critical, it is important that the U.S. continue to invest in fundamental research and basic science to develop alternative battery chemistries with properties that surpass that of current Li-ion.* This alternative battery chemistry strategy – through increased support for the National Science Foundation and the DOE Office of Science – is the pathway for the U.S. to regain its perch as the leader in battery technology and lead the world as it transitions. Finally, by working with universities, the US must actively train a new diverse workforce versatile with battery science and electrochemistry to build and develop the batteries of tomorrow.

In the past, the U.S. innovated in batteries, but didn't manufacture. Now, we need to manufacture and continue innovating.

The previous energy transition

Key takeaway: ***The U.S. has been through energy transitions in the past and innovated its way through supply chain related challenges***. ***It must do so again***.

Amid an energy revolution, it can often be difficult to place current happenings in context since the energy landscape shifts rapidly. But we can learn from the past with other energy transitions as well as the history of the current Li-ion battery. With the advent of the internal combustion engine in the early 1900s, numerous fuels could power the engine ranging from alcohol to gasoline. There are many suggested reasons for why gasoline (and petroleum) dominated but availability and cost were the most impactful. It was easy to source, especially from the United States. And with greater innovation on crude oil processing, it was cheap. However, as car manufacturing and deployment across all sectors of society soared, the U.S. became an oil importer. Dependence on foreign oil led to the oil shocks of the 1970s that made the U.S. realize how vulnerable it had become. Hence, diversification of the supply chain is paramount. Fortunately, innovation in drilling practices such as horizonal drilling, the ability to refine sour crude (crude with high sulfur content), and the proliferation of natural gas decreased the U.S.'s reliance on foreign oil and set the U.S. on its current path as the worlds' top oil exporter.[1] Innovation allowed the U.S. to regain world dominance. *From this history, it is important to emphasize that innovation, rather than diversification alone, played a primary role in regaining independence.* This history provides a lens with which to view the challenges that will arise in the current energy transition. Innovation and fundamental science discoveries must again play a pivotal role as the U.S. lags behind Asia and Europe in electrified transport.

Learning from the past

Key takeaway: Many Li-ion battery materials have been invented by Americans or in the U.S., but translation of these discoveries to the marketplace took hold in Asia and Europe. The U.S. must remedy this by incentivizing deployment across all parts of the supply chain.

America is ingenious in its continued drive to innovate. Batteries are complex devices but can be broken down into three primary components: anode, cathode, and electrolyte. The anode consists primarily of graphite, while the electrolyte consists of a lithium salt dissolved in a solvent. Many of the current supply chain challenges can be tied to the cathode.

The predecessor for the lithium-ion battery used titanium disulfide (TiS_2) as the cathode. Although sulfur is cheap, this cathode lacked the required energy densities (energy stored per mass and volume). Innovation by American and University of Chicago alumnus John Goodenough of the lithium cobalt oxide ($LiCoO_2$ or LCO) cathode set the Li-ion battery on the trajectory it is on today. Unfortunately, cobalt is the most expensive component of the cathode, and it is geographically limited. Work done in the U.S. at the University of Texas at Austin led to the discovery of $LiFePO_4$, a cathode material consisting of earth abundant and widely available materials. However, it suffered from lower voltages and lower energy densities compared to LCO. And so, innovation and research continued. At Argonne National Lab, the discovery of the

lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or NMC) cathode family decreased the cobalt content and increased the energy density. Hence, numerous electric vehicles today use the NMC cathode chemistry. Pivotal battery innovation happened here in the U.S.

Despite the U.S.-based and U.S.-led innovation in battery chemistries, America has lagged in translating these discoveries to the marketplace. Asian and European countries have been able to scale up U.S.-generated intellectual property and dominate the supply chain. Fortunately, the landscape is changing as the Bipartisan Infrastructure Bill seeks to shore up and diversify the supply chain, bringing mining and mineral processing jobs to North America. As value is added up the supply chain, onshoring battery material processing and manufacturing (anode, cathode, and electrolyte), battery cell fabrication and electric vehicle production is critical. Finally, at the end of battery life, onshoring battery recycling and reuse provides additional value-added opportunities. The recently enacted Bipartisan Infrastructure Bill (Infrastructure Investment and Jobs Act) acknowledges these challenges and provides funding and incentives to U.S. companies.

Supporting the present

Key takeaway: Current research efforts to deal with the critical mineral supply chain have focused on replacing cobalt with nickel in the cathode since cobalt is the most expensive component. However, this is only a short-term strategy. Innovation around alternative battery chemistries must continue.

As the U.S. invests in deployment and manufacturing, current innovation must continue. *Innovation focused on alternative battery chemistries beyond current Li-ion batteries is the ultimate disruptor and path to mitigating supply chain concerns and making the U.S. independent.* There are several current short-term and long-term research approaches. Promising short-term research efforts have focused on low cobalt cathodes or high nickel cathodes. While these cathodes now exist, there are no electrolytes to allow for their long-term cycling. Electrolytes are the component in the battery that allow for lithium-ion transport between the anode and the cathode. The interaction and interface between the electrolyte and anode as well as the electrolyte and cathode determine the cycle life, charging rate, and many other battery properties. *My research group at the University of Chicago Pritzker School of Molecular Engineering has invested heavily in designing new electrolytes that can allow these next generation cathodes to be used.* These electrolytes are synthesized, characterized, and studied in lithium-based batteries and my work has been supported by the National Science Foundation as well as fellowships from companies such as 3M and Toyota/Electrochemical Society. However, as the cathode chemistries focus on lowering or eliminating cobalt and increasing nickel, nickel will become an even more critical material. Hence, this strategy works only for the short-term.

Investing in the future

Key takeaway: Future alternate battery chemistries can eliminate critical materials, use earth abundant materials while enabling high energy densities for both applications in transportation and electricity generation. Continued investment in fundamental and basic science through the NSF and DOE Office of Science is critical.

As investment in manufacturing and deployment rise significantly in the U.S., it is paramount that research and development funding for alternative battery chemistries not only continue but also be prioritized. This is because the battery of the future may not yet exist today. ***That is why continued and increased funding appropriation for basic and fundamental research through the DOE Office of Science and the National Science Foundation is key.*** Unfortunately, the Bipartisan Infrastructure Bill does not explicitly fund continued R&D**.** Basic and fundamental research allows researchers to work on the alternative battery chemistry of the future that will allow the U.S. to lead and dominate the future of electric transportation. *During my PhD and postdoctoral experience and in my faculty career, I have worked on some of these experimental battery chemistries that are not ready today. But, with the right level of support and effort, these alternative chemistries hold promise much greater than the Li-ion batteries of today*.

One prominent chemistry involves completely replacing the current nickel and cobalt-containing cathodes with active materials like oxygen and sulfur. These new chemistries – termed Lithium-oxygen and Lithium-sulfur – can double the energy density of current Li-ion batteries, reduce the cost since they use abundant oxygen and sulfur, and de-risk the supply chain since these materials are available worldwide. However, these battery chemistries are plagued by the lack of suitable electrolytes. State-of-the-art electrolytes are unstable upon exposure to reactive oxygen species and lead to continued dissolution of the active sulfur active species. Research must continue on new materials, especially focused on electrolyte design.

Newer battery chemistries exist where the current Li-ion cathode is replaced by graphite. These batteries are termed dual-ion batteries as the salt anion also participates in the electrochemical reaction. While it is exciting that these batteries operate at high voltages, almost no electrolytes are stable at the high voltages they at which they operate. Again, this reinforces the need for continued fundamental understanding of electrochemical battery reactions as well as need for new materials. The afore-mentioned lithium-air, lithium-sulfur, and dual-ion battery chemistries can be deployed for transportation but also for the electric grid.

Beyond supply chain related challenges for the cathode, alternative battery chemistries that use lithium metal as the anode have been termed the 'holy grail.' The country able to solve lithium metal challenges and develop the infrastructure needed will dominate the electric future. However, there is still a dependence on lithium. Although the U.S. used to be a leading producer of lithium, the rise of cheaper extraction processes in South America (lithium brines) have usurped the U.S. position. Hence, innovation in mining – without environmental damage – and recycling/reuse is important. *I want to emphasize that these are fundamental research challenges, and if solved, can be deployed in the U.S. to lead to mining and manufacturing jobs*. Beyond lithium, there are advanced efforts for Sodium-ion (Na-ion) batteries that avoid the

potential geopolitical concerns of lithium but do suffer from lower energy densities. Finally, early-stage work on aluminum, magnesium, calcium, and fluoride ion batteries must continue to diversify the battery chemistries relevant for transportation, but also for applications beyond electric vehicles.

Investing in the future through academic research also necessitates a strategy to translate academic discoveries to the marketplace. This can be accomplished by providing capital and grants as well as a supportive regulatory framework for early-stage startups in the battery ecosystem.

Training talent

Key takeaway: A diverse workforce to perform STEM research, build batteries, and manufacture electric vehicles is needed. Here, universities have a pivotal role to play in training the next generation of battery scientists and electrochemists.

Significant effort must be placed on training the talent that will develop next generation batteries, build those batteries, and manufacture electric vehicles (EVs). This is an area where universities have historically shone. To prepare the U.S. workforce and equip them with the skills needed to innovate in battery and EV design will require a targeted collaboration between the government, industry, and universities. *Training women and underrepresented minorities in science, technology, engineering, and math (STEM) is important to ensure that all segments of U.S. society benefit from the energy transitio*n. Chemical engineering, mechanical engineering, materials science, and molecular engineering curricula will have to be modernized. *A curriculum heavily dominated by the thermochemistry of the past century will need to transition to electrochemistry for the next century.*

References

1. https://www.eia.gov/international/overview/world (Accessed April 17, 2022)

Chibueze Amanchukwu is a Neubauer Family Assistant Professor in the Pritzker School of Molecular Engineering at the University of Chicago. His research is focused broadly on sustainable energy technologies. His team is especially interested in understanding electrolyte behavior in a wide variety of electrochemical systems such as batteries and electrocatalysis. An immigrant from Nigeria, he obtained his B.S. in chemical engineering from Texas A&M University, graduating Summa Cum Laude and with the Best Graduating Student Award. He obtained his PhD in chemical engineering as a NDSEG Fellow at MIT and was a TomKat Center Postdoctoral Fellow at Stanford University. His work has been recognized with the NSF CAREER Award, ECS-Toyota Young Investigator Fellowship and the 3M Nontenured Faculty Award.

Chairman FOSTER. Thank you, and at this point, we will now begin the first round of questions, and the chair will recognize himself for five minutes.

Dr. Srinivasan, you described meeting the battery challenge as a once-in-a-lifetime opportunity. Dr. Amanchukwu said in his testimony that this moment in energy technology "could define the next century." The Administration and Congress have heard this call, and we have been putting a lot of—pulling a lot of policy levers to help. The *Infrastructure Investment and Jobs Act* had $7 billion in funding to support EV battery minerals programs.

Dr. Srinivasan, I mentioned you are familiar with all of these new funding streams, as Argonne will be a key player in carrying them out. With those in mind, if you had to identify one key research frontier that could still use more attention and resources, what would it be?

Dr. SRINIVASAN. Thank you, Congressman Foster.

I will maybe point out a priority of three that might be the most important to think about.

The first one I believe it's very important for us to think hard about substitutions for nickel and cobalt in these materials. I think that in the long-term, moving away from these critical materials is going to be important for us in the country to maintain the kinds of secure supply chains that we will need going to the future.

The second, which is maybe equally important, is to ensure that we are able to buildup the supply chain earlier in material refining and maybe on to capital and add-on materials. We do not have that as you pointed in your remarks, and I think it is important for us to build out that part of the supply chain to ensure that the many of the cell manufacturing plants that are coming up in the recent past are able to reach a point where they can get the supply of the materials from domestic manufacturing units.

And the last one is, I think, as the next 10 years, I view recycling as being critically important and incentivizing and providing the R&D support to make recycling cost effective is going to be extremely important for us to add to the supply chain of these materials.

Chairman FOSTER. Thank you.

Dr. Amanchukwu, do you have a favorite area that you think could use more effort and attention?

Dr. AMANCHUKWU. Yes, certainly. Thank you very much, Congressman Foster.

I think one especially important area is on innovating in battery chemistries that do not exist today. So, while we are trying to deploy lithium-ion batteries, there will be the incentive to focus on solving challenges with lithium-ion batteries. But we need to anticipate the challenges of the next 10, 20 years, and that often involves funding to the National Science Foundation and the Office of Science where there is no current target. So, "pie in the sky" ideas for battery chemistries.

And then the second point is on talent. Who will build these batteries here in the U.S.? Who will manufacture them? Who are the scientists that will solve these problems? This is where efforts, specifically from the Federal Government on emphasizing battery science and electrochemistry, to make sure that even with the de-

mand that we anticipate, that the U.S. can actually build these here in the U.S.

Thank you.

Chairman FOSTER. Thank you, and you point out that there's a lot of technological uncertainty in what materials will become crucial, and so, one of the key and difficult things that Congress faces is the need to sort of become venture capitalists and decide which minerals to invest in early.

China has clearly placed a big bet on lithium and first-generation lithium-ion batteries and won by that early investment in minerals processing. And so, do you feel that more could be done to partner with the minerals processing industry, at least for the minerals that we can see, are likely to be important, and what are the efficient ways to deploy Federal resources there to demonstrate new processing technologies and bring them to market?

Dr. AMANCHUKWU. I think, one, yes, there are certain chemistries that will continue to dominate. We know that there are certain chemistries that will be important. So, lithium, nickel, cobalt, and the U.S. used to dominate lithium processing, actually, in the early 1990's until it fell behind in terms of how to process these cheaply. And so, investing in companies that already exist as well as fundamental science and the research to come up with new ideas to process lithium, for example, will be important for any energy transition that will go on in the next century.

Dr. SRINIVASAN. If I can quickly add a comment to this?

One of the reasons why Asian countries were able to move ahead is because they had a roadmap of where they thought the market was going to be. I think it's important in the United States to think about where we think the markets are for the different transportation sectors and maybe even the good sector, ask what kind of chemistries might be the answer, three years from today what do we need, 10 years from today what do we need, and then start to build out the industrial base that allows us to meet those targets.

A little bit of that kind of road mapping exercise is going to be crucial for us as we think about how we are going to incentivize companies to do the things that will give them a sustainable, long-term future.

Chairman FOSTER. Thank you, and my time is up, so I will now recognize my colleague, Mr. Casten, for five minutes.

Mr. CASTEN. Thank you so much, Chairman Foster, and I am so excited to be here. I love that we are having this hearing, and not only because it's a stone's throw from my house and I got to see my kids before coming down here today.

I am an entrepreneur, and I sit there and I look at these numbers I just pulled up—and don't quote me on this, but it's on the internet so it must be true. 2019 U.S. demand for passenger electric vehicles, 2.1 million vehicles. 2020, 3.1. 2021, 6.7. We are in this exponential increase in demand, and all of the concerns that we hear is demand is growing faster than supply. I love that kind of problem, right? We can solve that and the fact that we are in Illinois, we have got this entrepreneurial spirit that we've not only got, you know, the foundational research that's happened at Argonne and our universities, University of Chicago, U of I, Lion, Rivian, the—Navistar up the road. We've got the people who are

building this infrastructure. I go to, you know, the union halls at IBEW (International Brotherhood of Electrical Workers) where they've got the training facilities. We're owning the future and it's awesome, and I just love that we're doing this. And so, thank you all for doing what you do and embracing that.

I do—I want to—and by the way, we also are generous. We don't—we share our wealth in Illinois. One of the first Loan Program Office investments was for Sierra Technologies down in Louisiana, so you're welcome, Louisiana. We are sharing with you.

I want to focus on some of the supply chain issues. I know we got time for multiple questions, so I probably won't get through all this first.

But Mr. Nevers, I want to start with you. Your boss talked about that, you know, we've only got 10 percent of the supply we need for the chain. I know you've talked about expanding your supply—your production in the U.S. I wonder, as you think about the supply chain, we've got basic materials, whether it's lithium or cobalt, where those are going to come from where the natural deposits are. We've got, you know, the first stage processing refining that oftentimes is going to happen close to the mine, you know, except in unusual situations. How much of the supply chain do you think you can—you know, we can put in North America as you think about building this out, and how much of the supply chain is just naturally going to be overseas? How do you think about that?

Mr. NEVERS. Well, thank you. That's a great question, Congressman, and I can get back to you with more details there. I think eventually, of course, depends on where we go with chemistries is, as the doctors had pointed out earlier on diversification. We're trying to onshore as much as possible. Eventually we would like it all, and some of that can be done with not only looking at some of the *Mining Act* on the table right now—*of 1872*—but allowing and changing how we permit.

For example, right now if someone were to stake a claim, the only way for locals to voice concern is to basically litigate. Whereas if you had a—I know we talked earlier about a road map. But if you went out and actually had a map of where the resources are and you could sell things to be a lease or you can get public comment up front, I think if you did that, you would fill in the supply chain, as it were, at least the raw material aspect.

As far as—what are they called—midstream, that could all be done here. We have refineries here doing similar things. We have the talent here. It's just realizing that, and again, once the batteries are here, keeping them here. Once they're here, they're a resource.

I don't know if I answered your question, but I can get back to you.

Mr. CASTEN. You know, that's great, and like I said, I know I am going to run out of time, but Mr. Baguio, I know you guys are manufacturing in Quebec, right? I'm curious how you think about the same question.

Mr. BAGUIO. Yes, we have a saying at Lion Electric internally that every one year at Lion is like five years everywhere else. So, when you——

Mr. CASTEN. I feel the same way about our job.

Mr. BAGUIO. Yes. So, when you look at what we're doing, because we are building a battery manufacturing plant just on the other side of the border in Quebec as well to produce 500 gigawatt hours per year. But that's not enough to feed the factory we're building right down the street.

So, it's—we are looking for additional domestic sources of these batteries, and you know, the outlook is good for the next two, three years from our standpoint of supply chain, but we can't plan a business in that short term.

So, I think the comment on having a long-term road map with measurable milestones to know that we're on track is going to be key to getting this considerable change in the way our economy works underway. And yes, the first phase is with lithium ion, and that's a big, lengthy phase. But new technologies, new chemistries are going to have to back that up as we start to try to power ships and planes and over the road trucks.

Mr. CASTEN. OK. See, I'm out of time, so I yield back.

Chairman FOSTER. Thank you, and the Chair will now recognize himself for five minutes.

Mr. Baguio, I guess we all remember the three R's, reduce, reuse, and recycle. Alternative chemistries will help us reduce demand for critical materials, and we can hopefully figure out how to efficiently extract and recycle minerals from the old battery cells into new ones.

But there's also an opportunity to reuse the entire battery pack. People are talking about taking batteries out of the EVs once they're depleted and stacking them up to create a grid scale energy storage device. Can you talk a little bit more about what Lion Electric is doing to prepare for vehicle to grid applications with your batteries?

Mr. BAGUIO. Yes, absolutely. We have participated in five V2G, vehicle to grid, pilot programs across the United States, and recently—as a matter of fact, yesterday—signed an MOU (memorandum of understanding) with the Department of Energy to more closely examine the usefulness of these batteries in a grid application so that once they come out of the battery—out of the vehicle, I'm sorry, there are other opportunities to power with other renewable sources such as wind, solar, and hydro.

Again, if we are taking the batteries from these vehicles that still have considerable energy resources in them, again, there are supply chain impacts. You don't have storage companies looking for brand new lithium ion when there is this vast resource across all of transportation, not just our vehicles, to fill that need for stationary storage.

Chairman FOSTER. Thank you. It sounds like your rate of degradation of the battery is, you said, one percent per year?

Mr. BAGUIO. Half of one percent per year.

Chairman CHAIRMAN. Half of one percent. That's under normal use?

Mr. BAGUIO. That's under normal use.

Chairman FOSTER. So, it's mostly 200 years before——

Mr. BAGUIO. And that's——

Chairman FOSTER [continuing]. Your battery pack is ready to be sent out to pasture?

Mr. BAGUIO. We'll see. We're tracking this, but the initial results are very encouraging.

Chairman FOSTER. Wow. So, are there other things that the manufacturers of automobiles and vehicles have to do to anticipate the recycling? I remember saying, you know, one of the new innovations in, I think it was Tesla, is to make the aluminum support frame for the whole thing being filled up with batteries, and I looked at that and said boy, that's going to be hard to recycle. Whereas if you have a, you know, a standalone battery pack that you can just pull out and use, it will be easier. Are there things that are anticipated or rules that government could set about ease of recycling that make sense to contemplate?

Mr. NEVERS. Good question. I'll note our battery packs are modular, so you can take out the individual modules. And what's great about that is the optionality. So, down the road you could either choose to recycle or reuse whatever made most sense for you.

As far as what government could do going forward, Rivian is for extended producer requirements guided by, actually, the Federal Government. Instead of having, perhaps, maybe 30, 40, 50 State programs, we could see that coming. That would be a nightmare on the regulatory side. We're all for zero landfill, no battery ever going to landfill again. It wouldn't make any sense to, because they're actually worth something now.

So, I don't know if I answered your question there, but there are things that you can do, including EPR (extended producer responsibility) and working with some of the States, including California and some other States who are already looking at implementing warranty and battery durability requirements that we're following closely.

Chairman FOSTER. Do any of our witnesses know, are there other countries that are doing a better job of specifying the recycling ability of things that are hitting the market?

Mr. NEVERS. So, right now, the European Union Battery Directive, which is under review, will set recycling requirements. Those will be effective probably in the next couple of years. I will note, we are concerned there that we don't want to specify maybe—we don't want to specify a mandate of recycling percentage, just because we don't know how many recycled batteries are going to be available if they end up lasting like we expect, 10-plus years. It's going to be a while before we can get them back and put them into new batteries.

Chairman FOSTER. So, you would prefer just sort of a structural requirements on you have to be able to remove the batteries efficiently, you have to be able to disassemble, perhaps, the individual cells rather efficiently?

Mr. NEVERS. Correct. We look more for extended requirements on the manufacturer, either battery take back or responsibility. They're coming anyway. Let's do them responsibly.

Chairman FOSTER. Thank you, and my time is nearly up, so I will now yield the next five minutes to Representative Casten.

Mr. CASTEN. Thank you.

Dr. Srinivasan, back in my misspent youth I spent a ton of time working on the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies) model, trying to understand the

impact of, you know, the total well-to-wheels cost and environmental impacts of various fuel choices.

I wonder if you can speak—you know, we talk in electric vehicles about the supply chain issues of electric vehicles, where it comes from, the environmental—as we should. Have you guys done any analysis of how that compares to conventional vehicles? You know, my sense is that we also need weird metals to make an engine block, and on a lifecycle basis, I would assume that we use a lot more imported material to run a car for 20 years than we need to run an electric vehicle. That's an oil joke, for those of you that didn't get it.

Have you guys, within GREET or some other context, can you speak to the—both in terms of domestic content and environmental impacts of conventional vehicles versus electric vehicles?

Dr. SRINIVASAN. So, the GREET model has looked very carefully at both the internal combustion engine-based vehicles and the electrically based engines. I'd have to get back to you on details of exactly what it says about domestic versus foreign, but I will note that in general, making an electric car tends to be more environmentally energy-use wise than a gasoline car, and that's because much of the energy used goes into making the battery itself. So, you can imagine making a battery is a high energy process. There's a lot of high temperature heating that happens in different stages. Mining processes also take a lot of energy and refining is actually oftentimes at high temperatures, which take quite a lot of heat.

One of the things that we think about quite a bit in the R&D space when it comes to the refining and the mining and the making of the materials is how do you make low temperature routes for those high temperature analogs? Just as an example, if you have to heat a battery cathode material to 800 degrees Celsius for many hours to make the actual crystal structure that you need, you're going to spend the energy by doing it either from a fossil fuel source or some sort of a hydrogen source to get that kind of heat that needs to be there. Instead, if you can find a different process, say, a solution-based process to make that same cathode material, then all of a sudden instead of using 800 degrees Celsius, you can decrease the temperature and that will—significantly, and if you can get the same characteristics or even better characteristics, then all of a sudden, the total energy use has come down. So, there is quite a bit of work but if you try to link what GREET is telling us about energy use in EV batteries, trying to see how to develop alternate processes so we can find a way to decrease the total energy use. And I believe that this concept has to go upstream all the way to even the refining of materials where we think about how much energy and water we are using, so that we can develop new processes.

So, one of the things that we want to do is integrate GREET into all of the innovations so that we're able to continuously use that as a metric to understand are we doing better than existing.

Mr. CASTEN. Can you compare that, though, because the domestic content, I expect we'll get back on that, but you know, it also takes a lot of thermal and electrical energy to pump oil, to refine oil, to run a cat cracker, to distribute it, and I'm doing that every time I fill up my tank with oil as opposed to just when I buy the

car and keep it for 13 years or whatever. How do those—just with conventional manufacturing, how do those balance out?

Dr. SRINIVASAN. Conventional manufacturing—electric vehicle manufacturing is more energy use than conventional manufacturing without taking into consideration things like the, you know, the extraction of oil. We're just talking about making the pack itself. So, then it becomes a question of what is the primary energy source? Are you going to use oil in one case or gasoline in one case? Are you using electricity? Where is the electricity coming from? I think in general, all of us know that renewable electrons for all electric cars is the best way to go, but if you can't do that, it's always better to sort of think about it in terms of going electrification, because we know that they're going to gain when we drive that electric car.

Mr. CASTEN. OK. Well, pivoting there to on the electric side. I just introduced a bill with Paul Tonko two weeks ago and I hope we get the appropriations. But I have a concern that because of this entrepreneurial challenge, we're seeing so much rising demand for electric vehicles. The—you don't have to grow very far before we need to build more generation, we need to build more transmission, we need to build more wires. We need to build them in the right places, which you know, not necessarily where the loads are right now. I'm hoping to get some money to the Department of Energy to fund that, but I'm curious if you've looked at that and have some sense of—just in order to meet the market demand we're seeing, how much supply do we need to add to the grid, and by the way, let's make sure it's zero carbon supply.

Dr. SRINIVASAN. Yes, so we've looked to ask the two scenarios one can think about in the United States. One where we have a grid across the country with the renewable generation at different bases and maybe nuclear to add onto that where we don't have to worry about moving electrons from place to place, and we can deal with intermittency of renewables. That scenario is expensive, but also requires us to have State rights, you know, kind of cross State transmission lines.

If that scenario doesn't work, then we have to go to distributor generation storage concept. The latter is always going to be more expensive because there's a lot of storage you have to buy, and storage can be expensive. But in the sense of looking at this right, if you were to go the latter route then the amount of batteries needed for the grid is going to be another approximately 6-terawatt hour to 8-terawatt hour. If you build transmission lines, you might be much lower, maybe 2-terawatt hour to 1-terawatt hour, somewhere in that range.

So, we've looked at that scenario to ask ourselves what the future could be, but certainly, I think the debate is on as to whether there's going to be a transmission line built country, or are we going to go more distributor generation and storage.

Mr. CASTEN. Thank you. I yield back.

Chairman FOSTER. Thank you. You can say a little bit more about that. In terms of grid storage, which is one of the things that I know I—both Sean and I worry a lot about, is there seems to be almost two problems. One is the day/night problem where you're talking about a battery where you're buying cheap electricity dur-

ing the day and selling it at night or vice versa, and so, that requires a battery that can hold its charge for 1 day and the capital cost that gets recovered, you know, bit by bit every day. Much more challenging is the seasonal variation where many places in the U.S. there are two to one or more ratios with the availability of renewable energy on a seasonal basis. And that seems like it's much tougher and may lead to different technologies.

Any of you have ideas on where you think the leading chemistries and the focus of effort on that much tougher long-term energy storage problem might lead?

Dr. SRINIVASAN. I can start and see what others have to think about this.

Congressman, you're exactly correct. There is a dual challenge, one that we call the short duration challenge, anything less than 10 hours, and the long duration, which is now everything beyond 10 hours. So, it can be multi-day. As you pointed out, it could also be seasonal. And the challenge gets harder and harder and harder the longer and longer we desire to store energy.

So, when we take seasonal, that's probably the hardest because of the lowest cost. Estimates are that we might have to be in the area of $10, $20 a kilowatt hour, just to give you some numbers. Today, the install cost is probably in the order of $250, $300 a kilowatt hour. So, we're talking order of magnitude decreasing costs for those applications.

In those chemistries, it's not even clear that we want to be thinking about, you know, manufacturing and pulling things out of the ground, because all of that takes money. So, I think we have to start looking at alternates like things like hydrogen as a means of storing energy. Unfortunately, that requires us to store the hydrogen, which means that the location matters a lot. So, it's going to work in some parts of the country, not in others. We have to think about extremely low-cost electric chemical storage using things like manganese and zinc and materials that we know are ubiquitous, easy to—available, but also should be easy to make into batteries so that every cost is going to come down dramatically.

We also, I think, should be thinking very, very hard about using other forms of storage, including liquid fuels that are easier to store and using that as sort of a backup as we go to the future.

I do think that R&D in long-term seasonal storage is going to be extremely important. As all of you know, the Department of Energy has announced the Energy Earthshot, in which one of them is a long duration storage shot, so I'm hopeful that as part of that, many of these ideas and more will be sort of part of the R&D portfolio.

Chairman FOSTER. And it's my remembrance—Sean may correct me if I'm wrong—but I thought that the—what they call long term storage is a matter of weeks, not truly seasonal.

Dr. SRINIVASAN. Right, they define long duration storage in the Department as anything more than 10 hours, and as you know, 11 hours can be a lot easier target. Three months is a significantly harder target. So, the way I think about this is you should think about the time of storage on one axis and the cost you can have on the other axis, and the cost comes down dramatically as you start going toward seasonal as——

Chairman FOSTER. Dr. Amanchukwu?

Dr. AMANCHUKWU. I think I will just echo some of what Dr. Srinivasan mentioned, and I think the big part of it is innovation in chemistries. The chemistries that can do this don't exist today. So, why is that a challenge? So, one, electrochemical reactions that you want to control, they lead to side reactions, and so, can you sustain them for weeks, months? So, that—calendar life. So, what's the calendar life of these new battery chemistries that have been developed? And while it is easy to see that we have iron or zinc in abundance, typically nature is not a favorable way of—also really difficult to make batteries, long-term batteries with. So, there's a lot of innovation and science that needs to be done, but the promise is there. If we can do it, we have an electrified future.

Chairman FOSTER. Thank you.

Now, the—one of the things we've done recently is that the *America COMPETES Act* is going to be authorizing large upgrades to the major user facilities operated by the Office of Science, predominantly at the National Labs. And you know, I've always felt that these facilities were crucial in that they enabled access to scientific instruments that are really outside the ability of individual universities to access.

Dr. Srinivasan, can you say a little bit about how such user facilities are important for moving this forward?

Dr. SRINIVASAN. Thank you for that. I will say two things. One is a computing facility. In the last 10 years in the battery space, the discovery of materials has been revolutionized because of computation. What used to be a Ph.D. thesis of five years is now maybe within six months because of the computational—come and accelerate discovery of materials. So, it is extremely important for us to continue to use those kinds of facilities to continue discovery and acceleration.

The second one I will call out is the Advanced Photon Source, which is the use of the cyclotron facility at Argonne National lab. We use this photon source for everything from new material discovery, but also to do science on things like manufacturing. So, you know, one thing that I want to emphasize is that science comes everywhere across the supply chain. Even an applied problem can be solved using a fundamental approach, and the APS (Advanced Photon Source) shows how to do that by looking at things like how our battery material is being made, what happens during the making of the battery material, what happens when you try to make an electrode in a battery, and try to understand the processes that occur there so that it can control them better and try to make them into something that can last a long time.

So, I think the use of facilities will continue to play an outsized role as we think about innovation and the future.

Chairman FOSTER. You spent that whole time talking about the APS without mentioning curing cancer.

Dr. SRINIVASAN. Yes.

Chairman FOSTER. Thank you. I will defer five minutes for Mr. Casten.

Mr. CASTEN. Thank you.

Dr. Amanchukwu, don't take this personally, but you hurt my feelings when you said that we needed to transition from an edu-

cation system based on thermochemistry to one based on electrochemistry. You gave me a flashback of as a chemical engineer when my former head of engineering, who was a double EE, said to me, you know, a chem E is just a double EE who couldn't handle the math. And it was painfully true, because once we got to imaginary numbers, I was really lost. So, no offense taken, but I'll get over it.

I do want to ask, though, how you think about sort of where we should be investing from an education perspective, because if we are making this move to electrochemistry, you know, I suspect there's a lot more before your line that we should—you know, your short line. What does that look like? How do we do that, and you know, given my own experience, it's hard, right? How do you—what do you envision we should be doing, especially at the Federal level, to help facilitate that transition in our work force?

Dr. AMANCHUKWU. Yes, I am also a chemical engineer, so we can relate to that comment.

So, I think there are multiple approaches that the Federal Government can take, and one is that you need to start early. So, if the benefits of the industrial revolution were not evenly distributed, so how do you make sure that young kids grow up to want to become scientists and maybe especially battery scientists, electrochemists. So, that's also investing in the education system, investing in training our teachers, equipping them with the skills that they need to be able to translate real world science problems in a way that a middle schooler can understand. That takes training. Investing—I'm probably biased, but the investing in early career faculty members or professors so that many institutions—many countries in Europe and Asia that there's greater focus on ensuring that early career talent have the support that they need. Research has shown they take the most risks in terms of scientific problems, and that's—those are the people we want solving battery problems. Yes, they can solve cancer challenges. That's great, but we also want those minds coming to battery science and electrochemistry.

And then finally, ensuring that even those who come into the States, into the U.S. to do this work, so international collaborators, can also stay here and contribute to the science that we've trained them to do. So, having them leave to go back to their own countries is also a loss to the United States. How do we keep the talent that we've already trained?

Mr. CASTEN. Hear, hear.

Question for all of you, and it builds up on—follows on some of what Chairman Foster was asking about the recycling and the recycling technologies. I'm wondering how you think about this in a world where the battery chemistry is rapidly changing, and you know, I've been to recycling facilities that really focus on getting, you know, chemically pure strains. You know, eddy current field separators. I've also been to other recycling facilities where—like some of the battery recycling facilities I've seen are sort of, you know, powdering the cathode down and saying we're still going to maintain the chemical composition of this thing, but put it in a pellet that can be reused.

Can we even confidently predict enough about where the battery technology is going to think about how we—what sorts of recycling facilities and technologies we should be investing in, or do we have to wait until the technology stabilizes to think about how to make sure that we do have a robust recycling industry on the back end? For any of you who have a thought on that, I'd love to know how you think about that?

Dr. SRINIVASAN. I will maybe start off by sort of noting that I think the way the battery industry is moving, we will constantly see this sort of stream that is coming into recycling is going to be an older material compared to the material that we want to be putting into a battery. The challenge, I think, is going to last for a few decades. You know, we don't have a solution for that. We've already seen this change happening with high metal content, cobalt content materials really coming into the market, because the batteries that were made 10 years ago are now going to have to be made into high nickel content.

So, for example, in [inaudible] the way we think about this as to ask how do we convert from one form of cathode to another form of cathode, so that we are always supplying the right cathode that seems to be the one that everybody wants to use at the time, but by starting with whatever input feed shows up, because that's the one that we put into a battery ten years ago. So, I think it's going to be important for us to constantly have that.

I will go back to the idea of a road map. I think if you had a road map of where we think things are going to be in the next five, ten years, it's easier to sort of plan these things.

Mr. NEVERS. Congressman, I would just add—oh, by the way, I'm a Chem E also.

But I would just say——

Mr. CASTEN. We can all cry on each other's shoulders later.

Mr. NEVERS. I would add, this is a good problem to have. The fact that technology is advancing, we are not stuck in one place. This is actually the best problem you could have. So, it will turn into basically another commodity tool, if you will, where a battery comes in one end and out the other end, you have a set of commodities. I think that's what we're seeing long-term, and we will have time. We'll have 8 to 10 years plus, based on some of the EPRs we expect to see. They set up those requirements to adapt.

Mr. CASTEN. Thank you. I yield back.

Chairman FOSTER. Thank you. I guess as a physicist, I will refrain from quoting what physicists say about engineers, which is probably the same thing that mathematicians say about physicists. So, we are probably—we know where we are in the ladder of snobbery in academia, I guess.

But let's—if we think a little bit more about, you know, sort of the future of vehicles and the recycling strategy. You know, there is sort of—there's a flashlight scenario where you'd plan on replacing the batteries many times over the lifetime of cars. However, there's the iPhone strategy where it costs so much to replace the battery, they might as well just get the next model. Where do you think the vehicle industry will be going in these? You know, both for frequent use vehicles like delivery trucks, and also for, you know, consumer vehicles?

One of my big worries in this is that we really want to deploy these batteries to avert CO_2 emissions, and the worst thing you can do is build a big, expensive battery pack that stays in the garage of some rich person. You actually want to get that battery out there and you want to charge and discharge it as many times as you can, you know, basically beat it to death as quickly as possible to avert the most C02.

So, where do you think the tradeoffs are going to be there?

Mr. NEVERS. Well, thank you for that question, Chairman. There's a lot of components to that.

First of all, if you want to make sure the vehicles are being used, there are other mechanisms that can be in place. For example, EPA is looking at an E–RINS (Electric—Renewable Identification Numbers) program as far as their RFS (renewable fuel standard) rule that will incentivize use. States also have clean fuel standards that incentivize use or displacement of conventional vehicle miles with electric miles. So, that's probably the first piece.

As far as how long will these vehicles last, it really depends on, I think, on the class. As you get into the medium- and heavy-duty vehicles, you're looking at decades and you will probably see more battery swaps than you will on light duty. With the light and medium duty, which is where our R1T and R1S are, you will probably see at least one battery swap if it were to last 15, 20 years based on our warranty that we have right now. But that's going to depend on the consumer, you know, in the long run.

Mr. BAGUIO. Yes, historically when you look at how long a vehicle's, you know, useful life is, you know, when you look at a school bus or a class six truck or a tractor——

Chairman FOSTER. I remember when I was a child, you know, there was an even money bet whether the car would just rust into a pile of junk, you know, before the drivetrain failed.

Mr. BAGUIO. Right, and historically, older meant dirtier and more costly, but with this EV future we are talking about, the platforms in medium- and heavy-duty are so robust you can run that chassis for decades, as was previously stated.

So, we're going to see more battery swaps once those come out. And also, when you are connecting your vehicle to the grid, you're going to see more cycles. So, those batteries will have to come out sooner. It's not just based on the vehicle's duty cycle, it's going to be based on what everybody wants from that battery, including utilities, and there instances even in Virginia where they are pulling the battery even before its done with its useful life as a source of energy to make the vehicle move, because they have other plans for stationary storage and microgrid.

So, I think it's going to be all over place, but the good news is older in EV doesn't necessarily mean dirtier and more costly.

Dr. SRINIVASAN. If I can add a very quick comment to that. I should note, I think, because you are on the record, I am also a chemical engineer, so I thought it was just important for me to say that.

One of the things that is happening in the battery community is we think it's extremely important, especially for the things that you guys were talking about—and also the need to use vehicle to grid on an ongoing basis, to have batteries that can last many dec-

ades. So, there is a lot of work going on in the battery community trying to understand why degradation occurs and how do we extend the life of these batteries?

Probably the biggest challenge that we are facing is predicting the life of the batteries. So, if something has to last 20 years and the applications are changing because we are suddenly going to V2G which we were not doing in the beginning, and we don't quite know how degradation is going to be impacted by how we are going to use the battery, and nobody wants to wait 20 years to find out what the life is. So, a big part of what we're doing is using tools like machine learning and artificial intelligence and use of facilities at the labs to start to think about how do we take early data, accelerate some of the mechanisms, and try to see how to predict the life of these things.

Chairman FOSTER. One of the concepts that was big about a decade ago was the idea of hot swapping batteries, and I guess that is sort of being reborn in China where they are doing long haul trucking by swapping. What is the status of that thinking in the United States?

Mr. BAGUIO. At this point, you know—and we have seen models for that as well in other countries. Israel is doing something similar. But it's—you know, there are so many duty cycles right now that are the first step for heavy duty EV that, you know, we need to check off that first step as well. There's so many duty cycles that are under 200 miles per day. Every refuse truck in the United States, school buses, we've already well talked about, dredge trucks going from ports of entry to distribution centers, very short miles. So, you know, we are very focused—and I am only speaking for Lion at this point. But we are very focused on active-duty cycles.

And as both of you know, our real focus is being able to hand keys to something, to a heavy-duty vehicle, and have somebody drive it that day. This is not years away. This is going to fit into your operation today when we hand you the keys. And I know both of you have been handed keys and have driven our school bus here in Illinois.

So, I think that is our focus now, but I think in a long-term view, yes, it will be part of our business plan to look at longer range vehicles.

Chairman FOSTER. Thank you, and I will remind everyone that when we did a lap around your building, I just completely crushed Adam Kinzinger for the lap time. I just want—five minutes for Mr. Casten.

Mr. CASTEN. Yes. Let's make sure we have that on the record for posterity.

The—with all respect to our colleagues, I love the fact that it's just Congressman Foster and I, because we really get to dig into the details having these multiple rounds, and it's—I appreciate going—taking the time.

I have a big, meaty question on the science and a big, meaty question on economics. I want to start with Dr. Srinivasan. I'm sorry, I keep struggling to pronounce your name. The—25 years ago when I was working as a chemical engineer, the conventional wisdom was that the automotive sector was going to go from lead acid to nickel metal hydride. Lithium ion was this interesting con-

sumer electronics battery that didn't really have an application in the auto sector. And of course, thanks to all the technological research, we have done that.

We have also basically run down the periodic table, right, in chasing sort of lower—higher mass densities, higher volumetric densities. We've gone from 200 molecular weight to whatever nickel is, 50-something, down to three. Are we at a practical limit on mass weight densities with lithium ion? You know, is that simple characterization right? And then separately, should we be thinking about fundamentally different chemistries in grid-based applications where we don't have the same weight constraints, as we think about how optimize the supply chains?

Dr. SRINIVASAN. Maybe I'll start off by saying we absolutely have a lot of room left with lithium-based chemistries, so we obviously have spoken a little bit about lithium-ion batteries, the fact that we have removed cobalt and nickel, but if you now move toward the kinds of chemistries that we have broadly called solid state, which is really based on lithium metal, it fundamentally changes the energy density constraints that we're going after. It allows us to not only use lithium metal instead of using graphite, which allows us to increase energy density by a factor of 30 to 40 percent, but it allows us to go toward cathodes like oxygen and sulfur cathodes that are much higher energy density than today's sort of transition metal oxide chemistries.

So, if you look at raw numbers—and I will be very careful here, because sometimes—energy densities are not what actually one can get. But in theory, one should be able to get significantly higher energy density, maybe as much as an order of magnitude compared to lithium ion. In practice, that is going to be very hard to do, only because these chemistries like oxygen and sulfur are very difficult to control, but we think there is a possibility of going somewhere between 2 to 2.5 x energy density increase based on these new chemistries. So, that is the first thing I will say.

The second one—and you picked on a very important point, which I think when we look at the grid, I was telling you some numbers before where we might end up requiring 5-terawatt hour or 10-terawatt hour of energy density for batteries for the grid. We need to think about a diversified set of supplies, and one important constraint we can remove is the energy density, volumetric and gravimetric. We don't have to worry about that. We have to worry a lot about, I think, multi-decadal lifetimes. Solar panels last 25 years, your battery cannot be replaced every 8 years. You have to think hard about safety. It is going to be extremely important to have very safe batteries.

So, I do think that as we look at the grid, we have to start thinking about chemistries that are low cost, are based on, say, water-based so they are not flammable, and that's where I think some R&D really is needed for us to get to the kinds of chemistries that move away from lithium. Today, there is a tendency to use lithium for both applications only because it is available. The economics are such that it is the one that makes the most sense, but I think we do have to start thinking about it from an R&D perspective, especially for applications on the grid side.

Mr. CASTEN. I want to pivot onto my big, meaty economics question. Mr. Baguio and Mr. Nevers, the—we're sitting here looking at this *COMPETES Act* that we're hopefully going to get through the Senate that's going to bring, you know, $57 billion, something like that, to re-onshore domestic manufacturing. We are seeing a whole lot of companies who are saying, you know, my lesson from COVID is these supply chains are too brittle. I need to bring more manufacturing back overseas, and we are seeing that in our economic numbers that for the last year and a half and for the foreseeable future, we're creating jobs a lot faster than we're creating workers.

I don't know how that doesn't lead to significant wage inflation, and everybody who has a job is pretty excited about that. Everybody who has to buy things from people earning higher wages complains about that, right? And I'm wondering how you, as you look at sort of the economic landscape, do you see that—I mean, how do we skin that cat? Do we basically say we're going to accept higher wages and therefore higher cost of consumer goods, and we're going to have a marketing solution how to fix that, or are we going to say, this 30-year trend toward—let's just offshore everything because it's cheaper, regardless of the consequences that we're not going to be able to separate that. How do you—I mean, we think about that a lot in our job. How do you guys think about that tension?

Mr. NEVERS. Thank you for that simple question, Congressman.

I would say we're trying to onshore as much as possible, and that means everything from battery production, vehicle production, to charger production. I would also say that one thing Congress could help with would really be streamlining the visas for skilled workers, and there are a couple reasons for that. Not just because you need someone for the job, but if you think of it this way, bringing in the right skilled worker might help keep more jobs in the U.S. So, that's probably what we're looking to do is push for greater access to international workers that have the skills so we can onshore. So, I think that's sort of the key enabler is being able to bring in the skilled people so you can keep all the rest of the jobs here, and onshore as much as possible.

Mr. BAGUIO. Yes, and I guess one component that maybe isn't real evident out there, but what we're trying to do is start earlier with the worker and work with STEM (science, technology, engineering, and mathematics) programs at the high school level and even middle school level in some cases. As you both know, the city of Joliet has the Nation's oldest junior college in the United States, and we are working closely with them to identify that worker at a very early stage, because workers that are just now entering the work force for the first time are very excited about EV. This is their reality where it may not have been the reality for us on the panel here. But starting early, developing some of those skills, whether it is manufacturing, whether it is engineering, early on and really creating that work force and steering them toward us as opposed to other things is part of a strategy that I think is going to work in this new, exciting field.

Mr. NEVERS. And if I may, I can get back to you later on some of the details that we, too, are working with both universities on training.

Dr. AMANCHUKWU. I can add something very quickly.

Not only do we start them young, but the changes in the transportation industry is going to affect those who are already in internal combustion engines. So, how do you reskill workers? How do you provide certificate programs? So, a lot of people who have already been trained on one technology to then equip them to be able to move on to a different technology, and that is also an important part of the portfolio.

Mr. CASTEN. Thank you. I yield back.

Chairman FOSTER. Now, if you talk about the very non-applied research, I'm—you know, things like transformative chemistries. Of all the papers that you read coming in, you know, what fraction come in from Europe, from the United States, from China, from Asia, the rest of Asia as a whole? And also, what fraction of them are sort of hidden inside stealth mode companies?

So, if you would just sort of give, you know, a quick guess as to what—you know, when you read an interesting paper, where does it come from these days?

Dr. AMANCHUKWU. I guess I can start. That's a tough question and I do not have numbers, but I think when we read interesting papers, they actually come from everywhere now, not just the U.S. The U.S. used to lead the number of innovations that came out, but that comes from everywhere in Asia, in China, in Europe also. And that's a good thing. I think that's an important thing for the transition. If only the U.S. transitions, we are still suffering from climate change problems. The entire world has to transition together.

But one thing that we have seen is that there has been greater investment in Asia and Europe on these technologies than we've seen here in the U.S., especially in the fundamental research and R&D. So, that's where we need more support, because we have world-class universities, we have world-class researchers that can bring in talent from everywhere. But how do we actually get them to work on battery and electrochemical related challenges?

Chairman FOSTER. Compared to, say, social media startups or Wall Street or crypto——

Dr. AMANCHUKWU. I wouldn't blame them. They pay more.

Chairman FOSTER. It's a cultural problem that somehow all the rewards in our economy go to the people with social media startups rather than the people that design the integrated circuits that make the whole thing possible. And the same thing is true of, you know, so much of our economy, you know, at the very end of the value chain, somehow that's where all the rewards come, and I struggle with that a lot.

Dr. SRINIVASAN. Some quick thoughts to that. I want to echo what Dr. Amanchukwu said, if you go back 20 years ago, I used to be editor of a journal where most of the papers used to be from the United States, Japan, and maybe Europe. Today, it has changed pretty dramatically. There's a lot of papers from all over the world, especially from China. That's just the reality, and that has been happening as a trend every year for the last 2 decades, I would say.

I will note, however, when you look at the startup culture, it does feel like United States still has that sort of real entrepreneurial spirit where we see a lot of ideas, especially compared to Europe

where we see a significant amount of lower sort of, I would say, you know—going after things in more of the sort of manufacturing. That is what we are seeing a lot more in Europe. So, the U.S. still continues to have that kind of, you know, sort of the entrepreneurial spirit where they're trying to take technologies from lab to market. My understanding is this is also increasing in Asian countries. There's a lot of emphasis there where they're trying to look at startups and new innovation, so I think we are going to see—we are in a world where competition is worldwide. We are seeing a lot of different things that are happening.

But the last point you made, Congressman Foster, I will note that in the last two years, something has changed in the battery industry. We are now seeing a tremendous, you know, talent has become a huge issue as we've all been talking about here. So, we see a lot of people looking at the energy sector, asking is that a way for them to get the riches, especially in startups. We've seen a lot of these special acquisition companies that have gone public and there's been a lot of stocks that have been issued to these companies, and to the employees. So, we are seeing the beginnings of a trend where we see, I think, the earlier carrier people choosing energy over software and seeing the financial incentives are going in that direction. I don't know if that's going to be a long-term trend, but certainly something that looks encouraging.

Dr. AMANCHUKWU. And just to quickly add, even those who are working on software, working on software for energy applications. So, how do you use—if you look at an electric vehicle, it is software-driven. Your battery management system, how do you predict battery lifetime as Dr. Srinivasan mentioned, all of that also uses expertise that has been developed for artificial intelligence for deciding is it a cat or a dog? Those technologies can translate to material discovery, and so, there is that—and young people are very interested in moving to energy storage, or just energy in general.

Chairman FOSTER. Yes, and so, there is a lot of sort of shared intellectual space between, you know, the study of how different proteins may bind together and the interactions when you get an ion inside a cathode. So, there's—and it's much more computational. It's not like old style thermochemistry where you've got a big vat of this at this temperature and doing something.

Dr. AMANCHUKWU. Thermal chemistry did power the industrial revolution, so it's played an important role in energy transition.

Chairman FOSTER. And I guess catalysts were always like that. There was always microstructure to be understood.

Anyway, I am now down to 10 seconds, so I'll turn it back to you.

Mr. CASTEN. So, the power of good staff, they are reminding me of areas that I should have followed up on earlier.

Mr. Nevers, I understand, if my notes are right, that back in 2019 I think one of your colleagues answered the question I was asking Dr. Srinivasan earlier. They said that the—over the life cycle, factoring in manufacturing and fuel use, that an electric vehicle was 40 percent lower CO_2 emissions? I see you nodding your head, so hopefully that's jogging memory.

Do you—I'm curious if that used the GREET models, and to what degree that assumption was based on a grid mix, and so as the grid cleans up, how much does that come down?

Mr. NEVERS. Well, thank you for the question, Congressman.

I'll get back to you on the GREET model aspect.

Mr. CASTEN. OK.

Mr. NEVERS. I'll have to get back to you on that, but I would point to a new study that came out last year from the International Council of Clean Transportation, and they actually revised those numbers. And now, it's 60 to 68 percent more efficient than an ICE, and that—when you talk about fuel mix, that's life cycle. That's average life cycle in the U.S., so that includes battery development or battery production, vehicle production, and fuel. And that's marginal—that's a marginal delta to ICEs.

Mr. CASTEN. I'm assuming you're making some assumption about the mix of fuels that form the power on the grid that you're using to charge that?

Mr. NEVERS. Yes. So, the paper came out last year, and it used a national average.

Mr. CASTEN. OK.

Mr. NEVERS. And I could forward that paper to you. Interestingly enough, there was another study done just recently. I think it was the Center for Automotive Research and maybe Ford that showed that some of the larger vehicles like pickups, when you displace gasoline pickup with an EV, you displace about 1–1/2 times more CO_2 than the similar passenger car. And why that's important for us is 70 percent of our customers are first-time EV buyers, so you're really—you're going at the market that really is the heaviest polluting chunk, if you will, and displacing those vehicles one at a time really—it's not just the 60 percent. It's the 1–1/2 on top of that.

Mr. CASTEN. OK.

Mr. Baguio, I understand that you started your career as a bus driver? Do I have that right?

Mr. BAGUIO. I did. Yes.

Mr. CASTEN. I'm assuming a diesel bus, probably.

Mr. BAGUIO. It was a diesel bus, yes.

Mr. CASTEN. It's got to be kind of cool that you now have something without a tailpipe on it that you're taking out.

Have you guys—we're talking about CO_2, but shifting to the criteria pollutants, you know, there's no shortage of research that not providing idle diesel buses, you know, especially in urban areas, not only has health benefits, but huge economic benefits because people live longer lives. I'm wondering if anybody—and this could be for you, given your history, or any of the rest of you through this. Have we looked at what that offsetting economic gain that comes from not having the health costs of particulate pollution and everything else that comes with that out of the back of the idling school bus?

Mr. BAGUIO. Yes. I can tell you that I did start my career as a school bus driver, you know, driving a route in between my college courses, and it was a great job. Eventually I became a general manager of large vehicle locations. So, you know, at one point I was in Los Angeles operating over 300 buses for the school district there, and you'd walk in at six in the morning and you would have that many diesel buses starting all at once. All of your employees walking into that environmental certainly affected our ability to

keep people at work and health issues, and we're still really understanding what the—you know, how magnified that was because of the environment. And your mechanics and all those other folks. So, there's certainly an impact in when you walk into, like, a Twin Rivers School District in Sacramento, California, where they are well on their way to converting to all zero emission, the environment for the worker every morning and afternoon is very different from what I experienced in the mid-'90's. There was also—someone smarter than me, an eighth grader in the Miami-Dade School District did a science project measuring diesel particulate inside the bus, outside the bus, in the classroom, and the worst air that her and her friends were breathing was inside that school bus going to school and going home. So, there's impacts on health. There's impacts on learning. A lot of things that can be measured economically certainly.

So, you know, making this transition to EV even more important.

Mr. CASTEN. Has anybody tried to quantify that? I mean, we—I spent a lot of time trying to get people to understand that we subsidized the fossil fuel sector in ways that distort capital allocation that we get away from it, and you know, to the extent that Medicaid is subsidizing the diesel fuel industry, it distorts markets. I'm wondering, has anybody tried to quantify those numbers and figure out, like, what is the scale of that cost we are accepting as a society?

Mr. BAGUIO. We have not done that at Lion Electric, but we do pay attention to organizations—non-profits like CalStart and the American Lung Association, the American Medical Association has done some things. But I haven't seen that, you know, dollar for dollar what are the impacts. There are certainly measurable statements in the, you know, loss of life and things like that.

Mr. NEVERS. If I may, Congressman. EPA is looking at new round of rules, 2027 and beyond for light duty and medium, heavy-duty vehicles. This would be hopefully in the regulatory impact analysis. Having worked there before, it's real easy to put in zeroes, and that's what you get for EVs. You put in zeroes for pollution. So, yes, we don't have those numbers either, but we're really excited because we have 100,000-unit contract or agreement with Amazon, and those are largely going to be displacing stop and go gas and diesel vehicles in some of these areas. So, maybe that would be a good question for some folks over at EPA, you know, what is the real-world air impacts of electrification, especially some of the urban areas?

Mr. CASTEN. I know I am out of time, but I see Dr. Amanchukwu, so if Chairman Foster will allow, I would welcome your response.

Dr. AMANCHUKWU. It's very quick. So, the Energy Policy Institute of Chicago is doing that research on trying to quantify the impacts of pollution and how that can be used for justifying the electric transformation.

Mr. CASTEN. OK, thank you.

I will yield back.

Chairman FOSTER. When we talk about, you know, securing the supply chains, does that mean securing the supply chain in the good old US of A, into North America into the free democracies of

the world? I guess—well, where does Rivian and Lion Electric, where do you view a secure supply chain as coming from? How are you handling that in your strategic planning?

Mr. BAGUIO. Obviously in our near-term plan, there is still heavy dependence on cells coming from the Asian market in general; however, you know—and again, to just to reiterate what an important topic is we're discussing today, but there's also efforts in Canada as we're opening battery manufacturing, working with both Quebec—province of Quebec and also Canada to identify sources that—mining sources that are going to feed that battery manufacturing. It is certainly part of our long-term goal, and also do that here in the U.S. We were looking at Joliet as strictly vehicle manufacturing, but we were really looking at probably having some battery manufacturing happening there as well to close that gap between the 20,000-vehicle capacity that we'll be building down the street versus the 17,000 vehicles that our battery plant will supply in the Province of Quebec.

So, you know, again, it's a phased process. We have to go where the batteries are so we can get these vehicles into people's hands, but looking at a North American, Central American, even in some cases, South American source has to be part of our longer term.

Mr. NEVERS. I would just add we're all for, I guess they call it ally shoring or leveraging existing diplomatic power, if possible, and really, that goes beyond just availability. It goes to sustainability and transparency. So, as part of our mission, we wouldn't want to—and I don't want to speak—but I think we all agree, we don't want to outsource just to find out later that maybe there was an issue with said outsource because there wasn't transparency or it wasn't done in a sustainable manner.

So, the extent we can onshore that's great, and ally shoring, I think, is important. I guess the question would be—back to the Subcommittee would be is there a way we can develop allies with the strategic goal in mind? We've done it in the past, obviously, you know, looking at different countries and why we're there. Why couldn't we do the same for these resources?

Chairman FOSTER. And I think that you are right that that's something that government really has a role in. You know, we have to decide where our incentives should apply to, you know. Should they be the free democracies of the world, which would be my preference. I have to say, I'm very impressed at the Biden Administration's stance toward that. They are saying we have to make our economy, you know, really not reliant on countries that we don't—shouldn't be trusting from the strategic point of view, or a human rights point of view. And the difficulty is how we set up the government incentives to make sure that you don't get your clocks cleaned by countries that offshore to cheap and abusive production facilities.

Go ahead.

Mr. NEVERS. Yes, I just wanted to add, we don't want to see this as a race to the bottom where companies are going to, as you mentioned, Chairman, to basically the country with the lowest common denominator in terms of environmental or human rights.

Dr. SRINIVASAN. Maybe make three quick points here. First is the Federal Consortium for Advanced Batteries, which was cham-

pioned by the Department of Energy that brings together DOE, DOD (Department of Defense), Commerce Department, State Department, other agencies, as really thinking about a holistic view on how to have a secure supply, including the sort of collaborations with allied countries. That's the first thing I wanted to point out.

The second point I wanted to quickly make is that for security, one needs a diversity of materials. So, the problem with cobalt and graphite is that they're concentrated in one country. So, having materials that have a wider availability in the world—nickel, for example, is one of them, actually—can provide us an opportunity to think about this from a secure way.

The last thing I'll quickly point out is that last year, the Argonne National Lab along with the DOE and the Department of Energy started a consortium called Li-Bridge which is really aimed at bridging the supply chain gap. It's a public/private partnership, and part of the public/private partnership is looking closely at where this road mapping exercise is going to go, and which part of the world do we have those kinds of materials. So Li-Bridge will be talking to this FCAP group and sort of making sure we are coordinating with the Federal Government so that we provide a view on what industry thinks the future is going to be, and how the Federal Government may be able to help us as we go to that future.

Chairman FOSTER. Well, when you figure that out, let us know. You know, trying to optimize the Federal subsidies for the right set of things is an ongoing challenge.

Let's see. At this point, I am done with questions. Mr. Casten, do you have additional?

Mr. CASTEN. Well, I will leave—maybe to put the question back to you all. You guys have been very generous with your time.

The—you know, this transition to clean energy broadly strikes me as being both enormously optimistic, because all the transitions make us—we have more money in our pockets because we don't have to pay for fuels anymore. We have cleaner air. We're creating all these jobs. And pessimistic because it is creating a tremendous wealth transfer from those parts of the world that have depended on resource extraction to those parts of the world that depend on having access to cheap energy. And that should be easy, but there are politics involved there.

There's a report I see out today that Blackstone has said that global decarbonization is a $50 trillion investment opportunity, and while the politics sometimes make it hard for government to lead, we can at least follow. And I'd love any closing thoughts that any of you have, if you were in our shoes, what would—given where capital is flowing, given how exciting and entrepreneurial this market is, if you could ask for one thing from Congress to sort of fix and make sure that it flows in a way that delivers the kind of social outcomes we want, what would you like to say to us?

Mr. BAGUIO. I'll start with that response, and I think a lot of what's happening or what we're seeing happening now especially with the *Infrastructure Investment and Jobs Act* that we're seeing the Federal Government in an unprecedented way really take action for zero emission technologies. But what I would like to see, the ask would be to really curb funding for legacy fuels, fossil fuels. I think we've decided as a society which direction we're going, and

whatever we can do to get there faster. We're trying to overcome over 100 years of fossil fuel culture, and it is going to take that initial push. But at companies like Lion and others like us, we understand that this investment means we get out range up, we get our prices down, and not just achieve parity with the legacy fossil fuels, but improve upon that performance.

So, you know, we would like to see continued unprecedented investment in this sector also, but also holding us accountable to achieve that eventual goal of giving something back better to the society of the United States that performs better than what we've just settled for for the last 100 years.

Mr. NEVERS. Thank you for the question. It's really hard to pick, but I guess that my ask would be an easier one, and that is first, do no harm, and when it comes to, for example, discussions around adjusting the 30D tax credit, do not exclude those manufacturers that have orders, have customers expecting a tax credit, but if there are some changes to that credit or a cap, it could really disincentivize future investment and future startups. So, that would be my concern there. First, do no harm on 30D.

Dr. SRINIVASAN. Maybe I'll quickly say something that I said in my earlier remarks. I view the energy transition as a two-prong problem, short term for the supply challenge, get these batteries out there, get us decarbonization as quickly as possible. But also as long term, to be sustainable, carbon-free, or completely sustainable materials supply, secure supply kind of a world.

And that second one requires long-term R&D. The first one requires more, I would say, combination of long-term and short-term R&D, and so, having a steady ship that sort of lasts those 10, 15, 20 years where all of these are incentivized would probably be the most important thing for us to ensure that we're able to move the transition and so that we don't end up with some fit starts or where we go in one direction and then have to change direction again.

So, I would say that steady ship is probably the most important thing.

Dr. AMANCHUKWU. Again, just echoing my earlier testimony, increase funding support to—for basic and fundamental science will always make the U.S. ready for whatever transition. Once we have the fundamental and basic research science happening here in the U.S., and building talent. Talent is key. It doesn't matter—any industry that comes, if you don't have the talent, you will not be able to sustain that industry. Those two things are key, two things from the Federal Government. So, increased funding for the NSF and the Office of Science at DOE, and building talent especially.

Thank you.

Mr. CASTEN. Thank you.

Chairman FOSTER. Thank you, and I guess I'll just close with agreeing violently with all of you, especially the last point. When you read one of those really impressive papers from some place you've never heard of before, we want to be able to hire that person and bring them into the U.S., and if they're some student, we want to—and we've trained them, we want to staple a green card to their Ph.D. thesis. It is something that we're hoping to get into the

COMPETES Act to really make that a permanent U.S. policy, which would be transformative.

You know, we're about to reach the point where the total cost of ownership of electric vehicles will be less than internal combustion vehicles, and that was only possible because of decades of federally funded research, and incentives to bootstrap the business. I think we should remember that lesson because it's only once we've convinced the world that zero emissions technologies are cheaper than fossil fuel technologies that we're going to be able to win the battle for climate change, not only in the United States which can afford to decarbonize our economy, but in the rest of the world we're not going to want to burn fossil fuels because zero emission vehicles are cheaper.

So, I want to thank you all for your part in that battle, and with that, we are looking forward to the Committee visit to Argonne National Labs, and we will be adjourned.

[Whereupon, at 12:45 p.m., the Subcommittee was adjourned.]

Appendix

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Venkat Srinivasan

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATIONS & OVERSIGHT

Questions for the Record to:
Dr. Venkat Srinivasan
Director
Argonne Collaborative Center for Energy Storage Science
Argonne National Laboratory
Submitted by Representative Bill Foster

Supply chain bottlenecks and related geopolitical risks associated with critical minerals used for EV batteries seem to be most acute at the processing stage. North America is responsible for virtually none of the processing operations for critical minerals. A few factors have led to Asian dominance over the west in minerals processing, but one of them is the environmental impact and resource intensity of traditional processing methods. Through the Energy Act of 2020, the Infrastructure Investment and Jobs Act, and other recent legislation, Congress has authorized and funded a number of new programs that can be used to support new processing technologies that would reduce cost, environmental impact, and/or risks to workers.

a. Do you believe that a physical test bed for piloting and demonstrating new technologies for critical minerals processing would help expedite the restoration of minerals processing capabilities in the United States?

We believe that a physical test bed focused on mineral processing has a role in accelerating the deployment of new process technologies that will aid in bridging the supply chain gap. In hard technologies, such as batteries, the "valley of death" to translate discoveries to deployment is partly due to the slow and complex scaling and processing requirements. Developing test beds have had a significant impact in accelerating this transition. An example is the Materials Engineering Research Facility (or MERF) located at Argonne National Lab, which is a world-leading materials scaling facility. MERF has demonstrated that such a facility can rapidly move newly discovered materials to a stage which is ready for industrial production. A similar facility, focused on mineral processing could accelerate the quest to achieve a secure supply chain in the US.

b. Would such a test bed be duplicative of efforts already being undertaken, or authorized by law to be carried out, by the Department of Energy?

While the DOE National Labs already have equipment that aid in mineral processing. These facilities should be leveraged and expanded on as much as possible. Further, an assessment of gaps in capabilities should be undertaken to determine areas for expansion of existing facilities, and the need for new facilities. In addition, we believe that there needs to be close connection between mineral processing and material synthesis to ensure that downstream requirements flow seamlessly into upstream technologies. Rethinking the needs for the US with these considerations in mind is vital for our long-term energy security.

c. If a test bed would be useful, what features would allow it to be most successful?

There are many different minerals that require processing across different technologies. There are multiple input sources that can be tapped for these minerals. In addition, the R&D community has been examining many different process technologies that can be brought to bear which promise to decrease

the energy and water use and ensure long term sustainability. Some of these process technologies are at a higher maturity level than others. A mineral processing facility needs to be flexible in accommodating these multiple constraints and allow different methods to be tested at different scales. Further, such a facility needs to be seamlessly linked to downstream processes to accelerate progress. Finally, close connection with industry is critical to ensure that new processes rapidly move to deployment.

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